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# Technology Review

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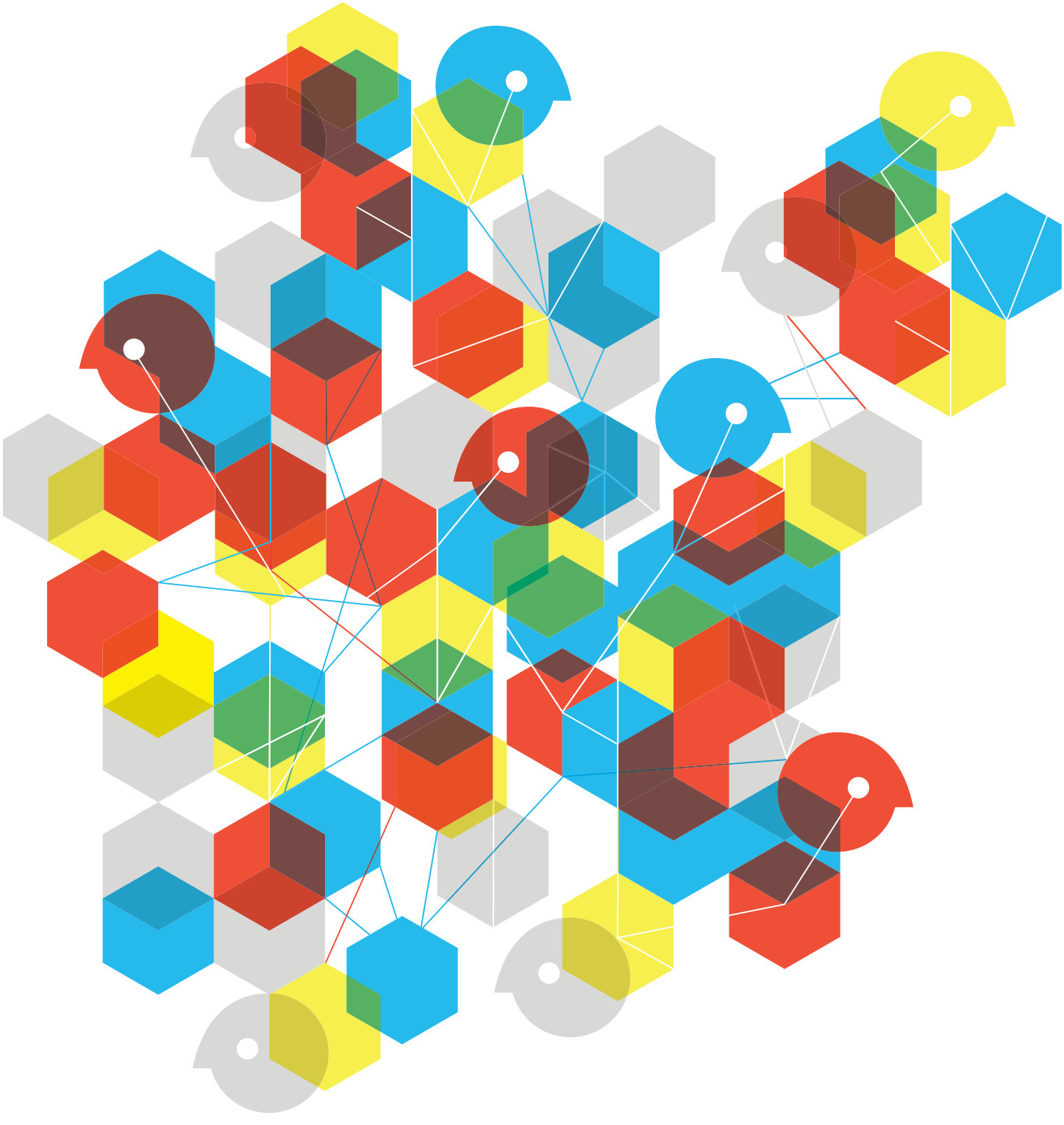

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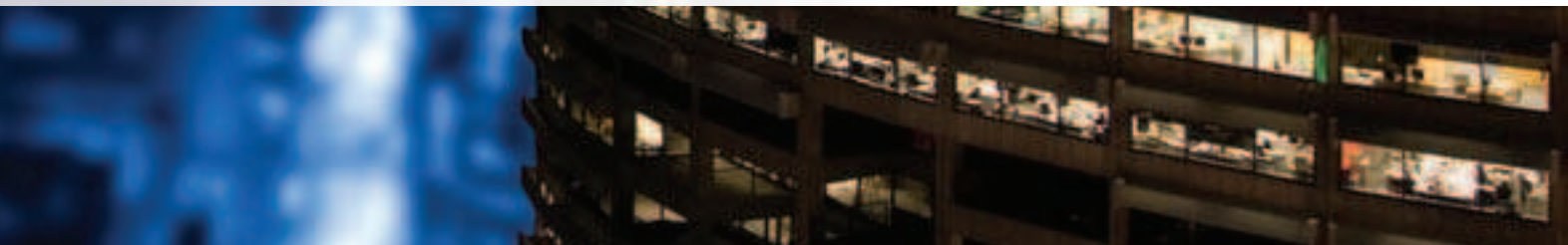

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# CONTRIBUTORS

In this issue's photo essay, science writer MOHEB COSTANDI looks at how the methods for examining the brain have evolved over the history of modern neuroscience (*"Time Travel Through the Brain," p. 26*). "Essentially, it is a pictorial history of neuroscience techniques," he says. "Early methods, such as the staining techniques developed by 19th-century histologists, are compared with their modern counterparts. Many of the images illustrate the rapid advances in microscopy that have occurred since the 1950s." Costandi writes a blog called Neurophilosophy, and his work has appeared in *Seed*, *Scientific American*, and *The Scientist*. He is writing his first book, on the brain and the self.

DAVID TALBOT, *Technology Review*'s chief correspondent, reports on the beginnings of data sharing among hospitals, a development spurred by the more than $21 billion that the federal government is projected to spend to support the widespread implementation of electronic medical records (*"Prescription: Networking," p. 34*). In the hours Talbot spent in the emergency department of Boston Medical Center, he was surprised by how much time the doctors and nurses spent hunched over computers. "It's not what you see on *Grey's Anatomy*; there is a good deal of tedium as they enter notes and pore over patient data, trying to learn what they can," Talbot says. "Patients are surprisingly uncommunicative about what's wrong with them, treatments they've had, or medication they're taking. Electronic records

can make sense of it all, especially when medical centers start sharing that information with each other." Talbot's 2008 feature on the Obama campaign's social-networking operation *("How Obama Really Did It," September/October 2008)* was selected for *The Best Technology Writing 2009* from Yale University Press.

JOSHUA J. FRIEDMAN discusses the efforts of graphic and type designers to transform the Web from a "font wasteland" into something far richer (*"A Note on the Type," p.76*). "When I first attended TypeCon, an annual conference of type designers, in 2006, people debated how to get more fonts onto the Web," he says. "This year, there was a sense that we're on the brink of that change. I think a great

typeface is like a well-crafted chair. It can be a work of art, but it fails if it can't do its job." Friedman, a former editor at the *Atlantic* and *Boston Review*, lives in New York City.

ROY RITCHIE took the photographs that accompany David Rotman's feature on how recently discovered sources of natural gas will affect our energy use (*"Natural Gas Changes the Energy Map," p. 44*). "The farmland

outside of Pittsburgh was absolutely beautiful," he says. "I was fascinated by how, amidst the scenery, the gas wells were almost inconspicuous." Ritchie recently traveled the world for the 2010 Ford Mustang ad campaign, and his work has appeared in *Time*, *BusinessWeek*, *Inc.*, and *Forbes*.


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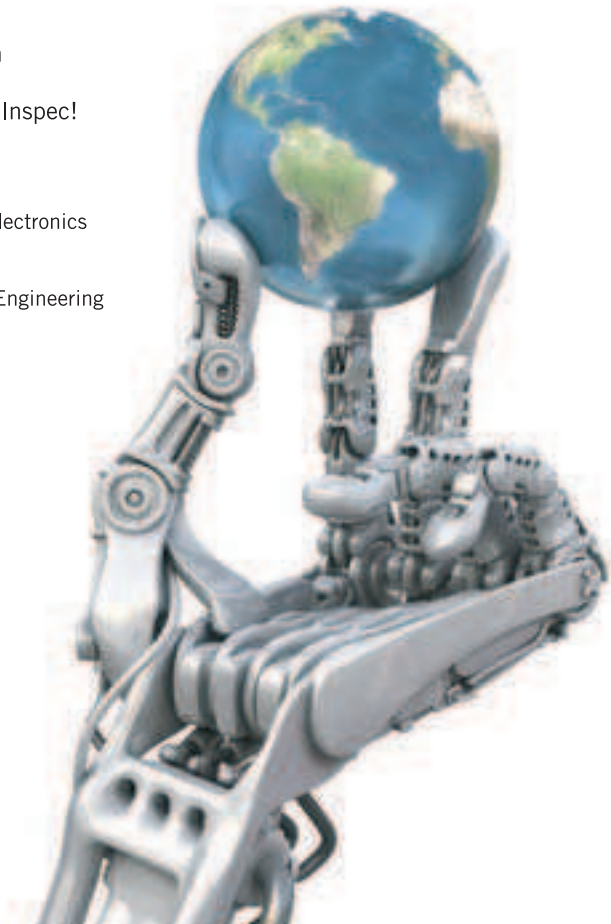

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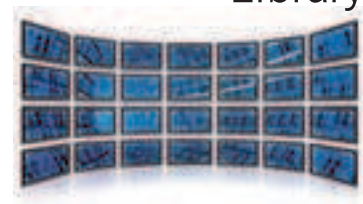

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### ALARMING INNOVATION

*Our profile of TR35 Innovator of the Year Kevin Fu ("2009 Young Innovators under 35," September/October 2009) explored the possibility that a hacker could interfere with the implantable cardioverter defibrillators that are designed to stop heart attacks in cardiac patients. One reader wondered if we weren't doing more harm than good in publicizing this aspect of Fu's work.*

September/October '09

I am familiar with these devices and would like to provide some basic information to calm any fears among readers who might have one in their chest. Traditional devices use decades-old communication links that require an inductive coil over the chest, requiring physical proximity to issue commands. The notion of a roaming attacker with a hidden inductive host is far-fetched; the limits of the near-field link would require the hacker to hug the victim. Newer devices include an additional short-range RF link for remote monitoring, but if you interview manufacturers you will learn that these devices are "read only" in this mode.

Mr. Fu's efforts are impressive, and his work in this area is extremely important and valuable. I hope his feedback to device manufacturers motivates improvements, and that together they can engineer even better solutions. However, I strongly believe this sort of feedback should occur off the pages of your magazine.

*Mike Timmons*
*St. Paul, MN*

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### GOOGLE'S NEW OS

*Commenters on our website had a lively debate over Google's announced operating system ("An Operating System for the Cloud," September/October 2009). One commenter wondered how Google plans to support it:*

www **Today's workers have been using Microsoft's OS since school; it was second nature to many by the time they entered the workforce. Google may not charge anything for the OS, but it will cost employers money to train support staffs and users. Cost of user support and interoperability with other applications are some of the challenges facing the Linux OS in the desktop market. Is Google ready to commit the required resources for an OS it will be giving away?**

*Patrick Opaola*
*Jersey City, NJ*

### LOCAL SOLUTIONS FOR GLOBAL PROBLEMS

*Our September/October Briefing focused on the prospects for renewable power.*

In "Solar Power Will Make a Difference—Eventually," the author presumes that ubiquity is a condition for a valid global solution, but the maps of the "energy belts" on page 97 are clear enough evidence that each region must respond to energy issues in its own way. Solar power, particularly, is now an economical solution in our sunniest climes. This fact has been disguised by—among other factors—an energy pricing scheme that defeats the investment value of on-site solar energy and other energy management strategies. We can't blame the tardiness of technology while we remain tardy in implementing transparent and equitable economic systems. The answer to the rather silly question in the opening section—"Can Renewables Become More than a Sideshow?"—is not only "Yes!" but "They must, and soon."

*Paul Symanski*
*Seattle, WA*

### THE WAY WE READ NOW

*One reader was intrigued by the potential of a new pressure-sensitive touch screen ("A Touch of Ingenuity," September/October 2009) that could be used in e-readers.*

I wonder if in the future we might need a new word to differentiate the kind of reading we do on computer or e-reader screens from the kind of reading we do on paper. I have heard a few new terms being bandied about on the Internet: screen-reading, browsing, skimming, scanning, even "diging." Reading is reading, of course. But we might not be "reading" the new and improved newspapers and magazines of the future. We might be "screening" them.

*Dan Bloom*
*Chiayi City, Taiwan*

### CONVERTING COAL

*A few readers wrote in response to Andrew Perlman's Notebook describing the process that his company is using to convert coal into natural gas.*

Although Andrew Perlman provides a compelling argument about the viability of the technology for hydromethanation, the statistics cited for the reduction in greenhouse-gas emissions discount the energy expended to convert coal into methane. Unless the energy for the process is derived from a renewable source, it would be disingenuous to claim that burning natural gas made from coal can reduce carbon dioxide emissions. Of course, a central part of the argument involves carbon sequestration, but perhaps direct sequestration from a coal-fired power plant is a more efficient way to reduce emissions.

*Han Sen Soo*
*Berkeley, CA*

*CORRECTION:* The TR35 profile of Shwetak Patel misstated his affiliations; he is assistant professor in the Department of Computer Science and Engineering and the Department of Electrical Engineering at the University of Washington.

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# Ghosts in the Machine

HOW MY PERSONAL EXPERIENCES PROMPTED "PRESCRIPTION: NETWORKING."

When I was a young man and very poor, I lived in West Oakland, a neighborhood of rundown Victorian houses on the flatlands east of San Francisco Bay, down by the Port. It doesn't matter how I came to be there: in brief, I had nowhere else to go.

This was years after the factories had left Oakland, when crack was like a plague, and long before the technology boom brought software and life-sciences companies, a new population that was middle class and ethnically varied, and developers who built lofts and restaurants for the new residents. When I lived in West Oakland, on the street where the Black Panther Huey Newton was shot as he left a crack house one bleary morning, few of us had regular jobs; the town was mostly African-American; and, of course, no one had health insurance. When we got sick, we went to the emergency room of Highland Hospital in East Oakland.

Once, a feral cat bit through the tendon in my right wrist. When my arm swelled alarmingly, Kenny D— (who paid for his habit repairing Chester Street's cars) drove me to Highland. I waited hours to be seen, more to be admitted. I wasn't impatient; there were others in worse shape. A young man, maybe 15 years old, had been shot in the leg and was handcuffed to a gurney, a kind of bloody, swollen diaper attached to his leg. He waited, too, while a fat, bored cop dozed beside him. I was delirious by the time I got a bed and antibiotics. I spent two weeks in Highland.

On another occasion, I noticed that the side of my neck was strangely deformed. Again, I went to the emergency room of Highland. They scheduled a biopsy. The lump was a tumor, but the harried doctors were uncertain: was it malignant? Weeks of ineffectual diagnosis followed. What was strangest of all (and what I don't understand now) was that I wouldn't say or couldn't remember the genetic condition that caused the tumor, which I had known about all my life. I was dazed by poverty and misfortune.

I lived in West Oakland after I had a job and the money to leave, fixed by some obscure spirit of loyalty. This time in my life made the strongest possible impression; I have never forgotten it, nor ever gotten over it. Oakland was my education in sympathy, and it formed what political feelings I possess. But my experiences there were never directly reflected in any of the magazines I have edited, which have been concerned solely with technology and science.

Recently, I saw a PBS Frontline documentary called *The Released*, which followed a group of poor, mentally ill men after they were released from jail. Each left with a bus ticket, $75 in cash, and two weeks' worth of medication. The men did badly in homeless shelters and group homes. They could not find work and did not take their medications; soon they were back in prison or dead. What reminded me of my time in Oakland was that none of the hospitals or clinics had records of which medicines had effectively treated the men's mental illnesses, and the men themselves wouldn't say or couldn't remember. They were ghosts. I was badly upset by *The Released* and wanted *Technology Review* to ask this question: Is there a technological solution to this small part of our larger health-care troubles?

David Talbot, our chief correspondent, found the answer. Boston Medical Center (BMC), which serves many of the city's poorer patients, has built a network of physician-based electronic records, linking the hospital with 10 community health centers (*see "Prescription: Networking," p. 34*). We were eager to learn if the network helped the people it was meant to help, so Talbot spent days in the emergency room of BMC. There, he met Vera Sinue, who had been admitted with unstoppable vomiting.

Talbot describes what happened next: "The attending physician, Aneesh Narang, was understandably worried. He asked if this had happened before; she muttered that it had happened only in childhood. A sudden and acute bout of vomiting might ... require speedy surgery. ... But Narang called up the electronic records ... [and] quickly saw that Sinue hadn't told the full story. In fact, vomiting was a chronic issue; it topped her list of medical problems. ... It's not clear why Sinue hadn't disclosed this information. (She later told me she might have forgotten.) ... [S]uch miscommunication 'is not really that surprising—we get it all the time,' says Andrew Ulrich, an emergency room physician who is also vice-chair of BMC's emergency department. 'You'd be amazed what people don't remember.'"

BMC's network is not sophisticated technology. The electronic records have neither genomic data nor images. But those records saved Sinue from a CT scan and a dose of radiation. She was given antinausea drugs and intravenous fluids. "Once the crisis passed," Talbot writes, "a talk with a physician revealed that Sinue was distraught over a personal issue. When the subject came up, she was overcome with nausea. She got a referral for what she probably needed most: counseling."

Often, a technology is "emerging" only in context. But when the context is suffering, it can make a small but important difference. Write and tell me what you think at jason.pontin@technologyreview.com. —*Jason Pontin*

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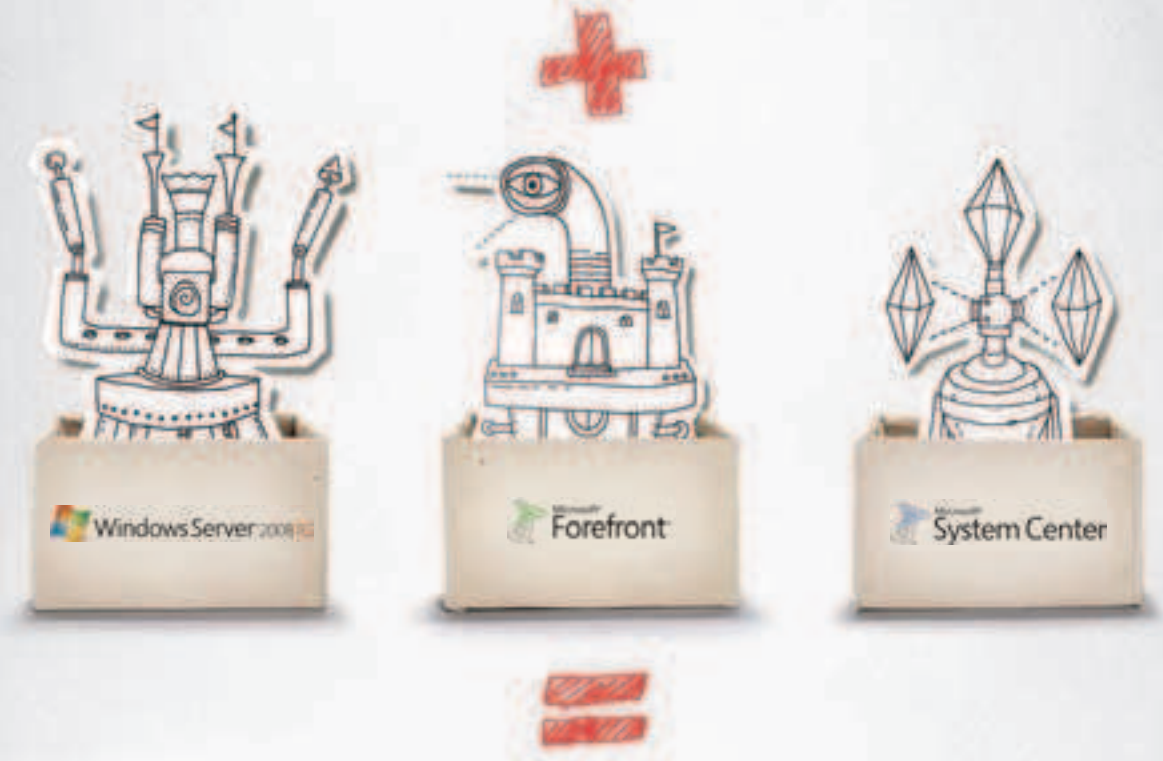


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# NOTEBOOKS
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ENERGY

## Clean Gas

DANIEL WEISS EXPLAINS WHAT IT WILL MEAN TO TAP THE COUNTRY'S LARGE SUPPLIES OF NATURAL GAS.

Natural gas is the cleanest fossil fuel—it produces half as much carbon pollution as coal, and one-third less than oil per unit burned. Recent advances make it affordable to develop the natural gas found in shale deposits, so we have more of this resource than was previously thought: at current production rates, there could be enough recoverable fuel to supply the United States for the next 90 years *(see "Natural Gas Changes the Energy Map," p. 44)*. This offers an opportunity to use natural gas as a bridge to a clean-energy economy that relies on efficiency, renewable power sources, and low-carbon fossil fuels.

The American Clean Energy and Security Act passed by the U.S. House of Representatives in June, aimed at reducing the pollution that contributes to global warming, would increase demand for natural gas. The bill requires power plants and other industrial facilities to reduce their emissions of carbon dioxide and similar pollutants by allotting them a diminishing number of sellable "allowances" to release these gases. This system would increase the price of electricity generated at old, inefficient power plants fired by dirty coal—making electricity from newer, cleaner, more efficient natural-gas plants more competitive.

The House legislation would also increase investments in wind, solar, and other sources of renewable electricity. Some of these power sources are intermittent—they generate electricity only while the wind blows or the sun shines, for example. Natural gas can provide backup power when these technologies are unable to generate electricity.

Natural gas could even replace petroleum fuels for buses, heavy trucks, and fleet vehicles. Proposed legislation would require federal agencies to buy alternative-fueled vehicles for their fleets; it would also create economic incentives for companies to purchase heavy vehicles fueled by natural gas. As a result of these policies, cleaner domestically produced natural gas would replace some of the dirtier imported petroleum we use today.

Other policies, too, could help expand demand for natural gas and decrease the pollution implicated in global warming. The starting price of pollution allowances should be raised to $14 per ton, which would come even closer to equalizing the price of electricity generated from coal and gas. We should create incentives to retire aging, inefficient, dirty coal-fired power plants and replace them with renewable and low-carbon electricity. And we need to conduct research on more efficient turbines, effective strategies for capturing and sequestering carbon emissions, and better ways to store power from renewable sources.

We must also adress the problems associated with "fracking," a process involved in drilling for shale gas, which can pollute air and water. Any program to increase demand for natural gas must include additional environmental safeguards, such as comprehensive scientific analysis and a requirement that gas producers report their use of toxic chemicals.

Expanding the market for natural gas would increase America's energy independence, reduce the emission of greenhouse gases, and create jobs. None of these benefits, however, will occur without comprehensive legislation. TR

DANIEL J. WEISS IS A SENIOR FELLOW AND DIRECTOR OF CLIMATE STRATEGY AT THE CENTER FOR AMERICAN PROGRESS.

MEDICINE

## Do No Harm

THE ANCIENT GREEKS CAN HELP GUIDE THE USE OF TECHNOLOGY IN MEDICINE, SAYS STANLEY REISER.

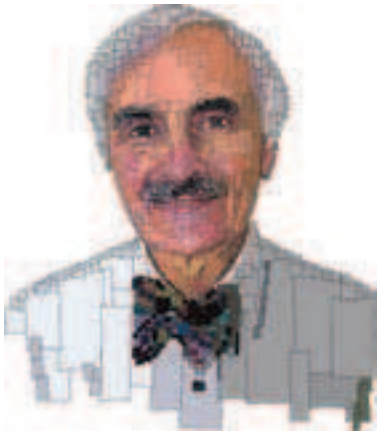
We live in an age of technological medicine, benefiting greatly from its probings and treatments. Yet patients' encounters with it can leave much to be desired *(see "Prescription: Networking," p. 34)*. In addressing those deficiencies, there is no better place to begin than a text produced 2,500 years before the modern technological era.

The work is an essay called "The Art," produced by Hippocrates and his disciples in ancient Greece. In his time, practitioners of medicine considered their discipline to be an art, not a science. This meant, in essence, that doctors knew they must use their ethical judgment to direct the limited number of interventions in their therapeutic arsenal.

The Hippocratic physicians were concerned that intemperate use of these

NICK REDDY/HOFF

therapies could have damaging consequences. Applying them inappropriately, to illnesses where they were unlikely to help, undermined patients' confidence in the treatments, the doctor, and medicine itself. It also transgressed an important principle of the Hippocratic Oath: do no harm. This precept is often misunderstood to mean that doctors must not inflict harm in the process of care. This



is frequently impossible: we accept pain and side effects as the price of beneficial treatments. What "do no harm" means, as I interpret it, is that doctors must avoid exposing patients to preventable risks.

The cautions expressed by the Greeks are worth respecting in the medicine of our own day, when technology is too often used without regard for the ideal of avoiding needless risk. A recent study estimated, for example, that about four million Americans have been exposed to a substantial amount of radiation from multiple imaging tests such as CT scans. While such technologies can be important elements of clinical care, doctors are increasingly using them to evaluate patients without clinical symptoms of disease. And each new test adds to the cumulative radiation dose that increases a person's risk of developing cancer.

The use of imaging tests is part of a larger trend in medicine: interrogating the body intensively and the person minimally in trying to prevent and treat disease. We need to pursue relationships with patients to understand how they live and function, not just use technology to secure biological data about them. To know and treat the disease fully and the person partially is a formula that produces inadequate medical care. TR

STANLEY JOEL REISER IS CLINICAL PROFESSOR OF HEALTH-CARE SCIENCES AND HEALTH POLICY AT THE GEORGE WASHINGTON UNIVERSITY SCHOOL OF MEDICINE AND HEALTH SCIENCES.

COGNITION

# The Nature of Intelligence

ROBERT PLOMIN EXAMINES THE POTENTIAL ROLE OF GENES AND IQ IN EDUCATION.

Today, few scientists—or even members of the wider public—question the existence of a general cognitive ability that is substantially influenced by genetics. In a survey of 2,000 parents and teachers, more than 90 percent accepted that nature (genetics) is at least as important as nurture (environment) in the origins of intelligence *(see "Intelligence Explained," p 52)*.

Research on intelligence has moved beyond the nature-versus-nurture issue to investigate *how* rather than *how much*. My team, for example, has discovered that the genetic influence on IQ becomes more pronounced during development. In a study of 11,000 pairs of twins from four countries, we have recently shown that the heritability of IQ increases linearly from childhood (about 40 percent) to adolescence (about 55 percent) to young adulthood (about 65 percent). Why? No one knows, but my guess is that the answer involves what is called genotype-environment correlation: as children grow up, they increasingly select, modify, and even create their own experiences, partly on the basis of their genetic propensities. A child genetically inclined

toward high verbal skills might choose to read more, enhancing those skills.

We have also found that the same set of genes affects different mental abilities. Genes that affect verbal abilities, such as vocabulary and verbal fluency, are largely the same genes that affect nonverbal abilities, including spatial visualization and memory.

Although these findings have far-reaching implications for educational policy and practice, the field of education has scarcely begun to take the nature of intelligence seriously. Heritability does not imply immutability. Nonetheless, the pervasiveness of genetic differences suggests that we must reëxamine the role of education. Instead of thinking about it as a way of countering genetic differences among children, education might profit from accepting that children differ genetically in how and how much they learn. Understanding the nature of intelligence is compatible with the current trend toward personalized education.

Finding a genetic influence on intelligence does not mean that we ought to put all our resources into educating the best learners and forget the rest. This finding could be used to argue for devoting more resources to genetically disadvantaged children. The relationship between knowledge and value is complicated, but there is nothing to be gained by pretending human differences do not exist. TR

ROBERT PLOMIN IS A PROFESSOR OF BEHAVIORAL GENETICS AT THE INSTITUTE OF PSYCHIATRY AT KING'S COLLEGE LONDON.

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# TO MARKET


E-READERS

## KINDLE KILLER?

BARNES AND NOBLE is partnering with Irex Technologies to market an e-reader that can download books over 3G cellular networks. (The bookseller will charge $9.99 for new releases.) The new device differs from the Kindle reader in that its 8.1-inch display functions as a touch screen, operated with a stylus. It also supports a wider range of open e-book formats than the Kindle, such the popular ePub format. Irex hopes to release a color version in 2011.

**Product:** Irex DR800SG **Cost:** $400
**Availability:** October 2009 in U.S., early 2010 in Europe. **Source:** www.irextechnologies.com
**Companies:** Irex Technologies, Barnes and Noble

JOSHUA SCOTT

AUTOMOTIVE

## Talking to the Grid

PLUG-IN HYBRIDS, which recharge their batteries from the utility grid, could strain that system by increasing electrical demand. Ford is getting around the problem by equipping its plug-in, the Escape, to communicate with smart meters provided by utility companies. As demand varies through the day, so does the price of electricity. The Ford system can be programmed to charge the car when that cost falls below a user-determined threshold or to charge only at certain times of day. Future versions may allow users to request electricity from renewable sources such as wind and solar. The first Escape fitted with the system has been delivered to American Electric Power in Columbus, OH, for testing.

**Product:** Vehicle-to-grid system **Cost:** N/A **Source:** www.ford.com **Company:** Ford Motor Co.

INTERFACES

## A TOUCH OF VEGAS

THE WORLD'S LARGEST public multitouch display, at the Hard Rock Café in Las Vegas, allows up to six customers to browse through a database of music-related photos and videos using touch controls. The 5,760-by-1,080-pixel display, which is 5.5 meters long and 1.2 meters tall, relies on three HD projectors powered by custom-programmed graphics processors. More than 100 images can be viewed simultaneously, and the system makes extensive use of data caching to prevent one user's commands from stalling another user's activity. Users' "workspaces" can expand, contract, and position themselves automatically as multiple patrons make contact with or walk away from the display.

**Product:** Rock Wall **Cost:** Not disclosed **Source:** www.obscuradigital.com **Companies:** Obscura Digital, Hard Rock Café

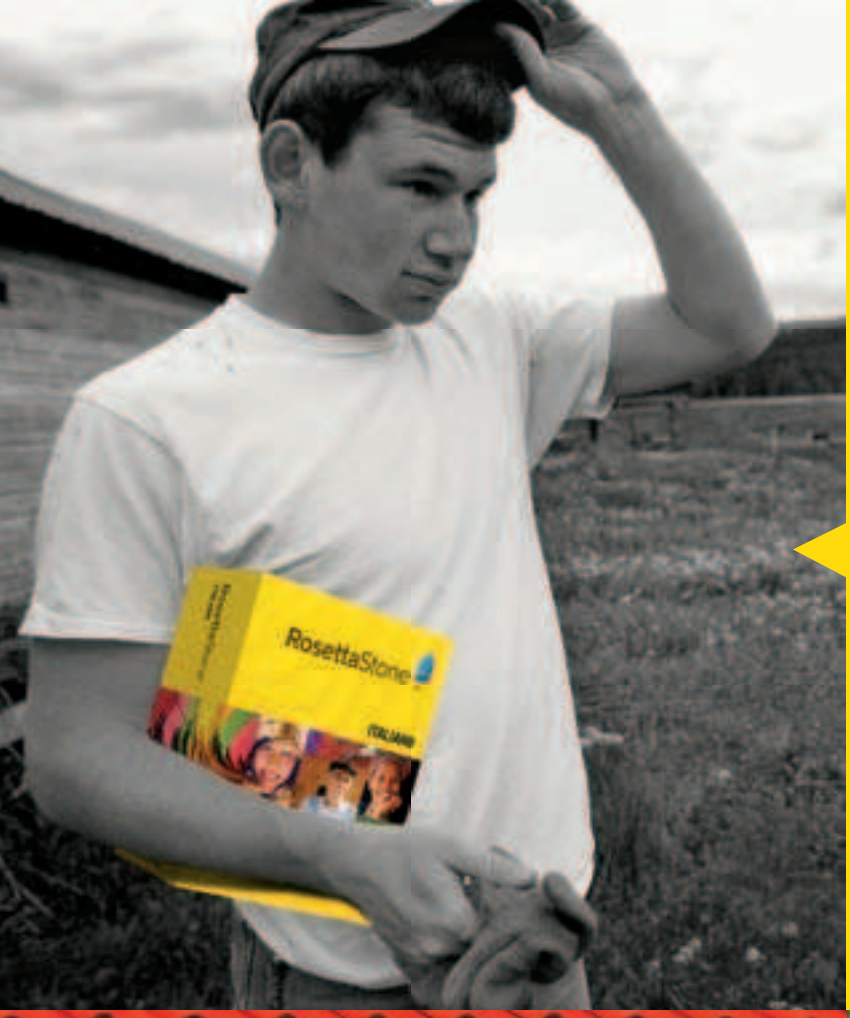
BIOMEDICAL

## CATCHING AUTISM EARLY

INTERVENTIONS FOR AUTISM are most successful if they begin between two and four years of age, but the average age at diagnosis is nearly six. The LENA Foundation has developed a screening system that can be used with children as young as two. The child wears a digital recorder all day long. After recording up to 16 hours of audio, parents mail the recorder back to the foundation, where software is used to comb through the child's vocalizations in search of patterns that indicate a high risk of autism. Parents are advised to consult a specialist if such patterns are found. The foundation says the tool can detect autism in children with the disorder in 91 cases out of 100.

**Product:** LENA Language and Autism Screen **Cost:** $200 **Availability:** Now **Source:** www.lenababy.com **Company:** LENA Foundation

COURTESY OF FORD (GRID); COURTESY OF OBSCURA DIGITAL (VEGAS); JOSHUA SCOTT (AUTISM)

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# PERCEPTION UPGRADE

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## Street Sense

AN iPHONE 3GS application from Acrossair offers a new way to navigate the urban jungle of several major cities. The system uses the iPhone display as a viewfinder for the phone's built-in camera. Pointing toward the ground will call up arrows indicating the locations of all the city's subway or light-rail lines. Holding the iPhone horizontally will overlay labels on the scene identifying the locations of the nearest stations, along with the distance to each one and the lines it serves. Acrossair has released versions for New York, Chicago, San Francisco, Washington, DC, Barcelona, London, Madrid, Paris, and Tokyo.

**Product:** Nearest Subway **Cost:** $1.99 **Availability:** Now **Source:** www.acrossair.com **Company:** Acrossair

JOSHUA SCOTT (MEDIGAIT)

## SENIOR MOMENTUM

FOR ELDERLY PEOPLE with diminished senses of touch and sight, loss of feeling in the feet can make it difficult to walk. The Israeli company MediGait, headquartered in Bar Giyora, has come to their assistance with GaitAid, a wearable display system that reëstablishes the feedback usually provided by tactile sensation. A person wearing the display visor sees a high-contrast checkerboard pattern. A pedometer-like device worn on the waist detects heel strikes and makes a sound whenever the wearer's foot touches the ground; it also repositions the checkerboard to provide a visual cue. MediGait says that users who practice with the device for 20 to 30 minutes at a time can achieve significant improvements in mobility even when not wearing it.

**Product:** GaitAid **Cost:** $1,995 **Availability:** Now **Source:** www.medigait.com **Company:** MediGait

# BRINGING BOOKS TO LIFE

TEMPLAR PUBLISHING has released the U.K.'s first book to be enhanced with augmented reality. Using a webcam and a software plug-in developed by Total Immersion, owners of *Drake's Comprehensive Compendium of Dragonology* will be able to access the special feature by holding up a particular page to their computer screen. The software uses markers on the page as spatial reference points, allowing it to draw a 3-D model of a dragon above the image of the book on screen. Owners can rotate the book to view the dragon from different angles as it moves and roars.

**Product:** *Drake's Comprehensive Compendium of Dragonology* **Cost:** Approximately $24.00 **Availability:** Now
**Source:** www.templarco.co.uk **Companies:** Templar, Total Immersion

To see an augmented-reality book, visit **www.technologyreview.com/arbook.** Take a snapshot of this code to read a special report on smarter IT. For the software, visit www.neoreader.com


JOSHUA SCOTT (BOOK); COURTESY OF LAYAR (REALITY BROWSER)

# Annotated Areas

WITH THE Layar Reality Browser from Sprxmobile, users of Android-based smart phones can see links to geographically relevant information—real-estate listings, restaurant reviews, Wikipedia entries, and more—overlaid in real time on camera views of the surrounding scenery. Users can choose what kind of information they want to see: for example, a Londoner working near Big Ben could see Twitter posts from nearby friends, while a tourist visiting the same location might see pointers to historical and tourism-related Web pages.

**Product:** Layar Reality Browser **Cost:** Free **Availability:** Now **Source:** layar.eu **Company:** Sprxmobile

DISPLAYS

## LOW-POWER SCREENS

A SAN FRANCISCO–based startup is developing low-power displays that are easy to view in bright sunlight. Pixel Qi's first color displays, which are intended for mobile devices such as e-book readers and netbooks, have already begun mass production. The displays use between a quarter and half the power of conventional LCD screens, giving a typical netbook about an hour of additional battery life. A reflector behind the screen allows the device to take advantage of ambient light, and the display, unlike an LCD screen, refreshes only when necessary. Pixel Qi was cofounded by Mary Lou Jepsen, who was the first CTO of the One Laptop per Child project.

**Product:** 3Qi **Cost:** Not disclosed **Source:** www.pixelqi.com **Company:** Pixel Qi

COMMUNICATIONS

## Tying Down Android

MOST BUSINESS desktop phones are primitive devices compared with modern cell phones, but Glass can integrate with Microsoft Outlook using a Wi-Fi or Ethernet connection, allowing contacts to be dialed at the tap of a finger on the eight-inch screen. It also allows access to popular online applications such as Salesforce.com's customer relationship software. The phone uses the Android operating system, which is normally associated with mobile devices; Cloud Telecomputers chose this Linux-based OS for its small footprint.

**Product:** Glass **Cost:** $600 to $700
**Availability:** Early 2010
**Source:** cloudtelecomputers.com
**Company:** Cloud Telecomputers

HENRY WESTHEIM / ASIA PHOTO CONNECTION (PIXEL QI); COURTESY OF CLOUD TELECOMPUTERS (ANDROID); COURTESY OF PLANON SYSTEM SOLUTIONS (PRINT)


MOBILE DEVICES

## HAND PRINTS

PLANON'S MOBILE Enhanced Print Application enables users of BlackBerry smart phones to print practically any Web page or e-mail attachment using one of the company's thermal printers. These portable printers connect directly to a phone, but until now only basic text files, such as e-mail messages, could be printed from a BlackBerry. The new application converts PDFs, word-processing documents, image files, and more into a printer-ready format using a remote server and transmits the result back through the device to the mobile printer.

**Product:** Mobile Enhanced Print Application **Cost:** $30 per year **Availability:** Now
**Source:** www.planon.com **Company:** PlanOn System Solutions

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Q&A

# DAVID BLUMENTHAL

## Health IT's billion-dollar man

By one estimate, only 17 percent of U.S. doctors use electronic records. But the federal government has ambitious plans to create a network in which patient information is shared electronically among medical institutions. As National Coördinator for Health Information Technology, David Blumenthal is writing the rules under which the federal government will spend more than $21 billion in stimulus funds to get the job done (*see "Prescription: Networking," p. 34*). Blumenthal, previously a practicing physician at Massachusetts General Hospital in Boston, spoke with David Talbot, *Technology Review*'s chief correspondent.

**_TR_: How long will it take to create a national health-information network?**

Blumenthal: The president has said that everyone will have an electronic health record by 2014. That is the goal we are working toward right now. We are trying to make the network available as fast as we can.

**Can health IT reduce the skyrocketing U.S. health-care costs?**

The Congressional Budget Office projected dollar savings from the [stimulus] legislation at about $12 billion over 10 years. I expect that the actual savings will far exceed that amount.

**How do we get around the potential problems with electronic systems—such as overwhelming physicians with data or actually causing medical errors?**

Electronic health records and other forms of health IT can certainly be improved, and there are examples of bad implementation and other problems. I still think that on the whole, across the country we'd be better off with universal availability of electronic health records. We'd have fewer errors, fewer missed diagnoses, less duplication of tests, and fewer adverse drug events.

**If health-IT systems reduce such errors and lead to fewer needless procedures, why haven't the insurance companies stampeded to get them installed?**

The insurance companies have been able to pass along the costs of waste in our health-care system to their clients.

**You are setting the definitions of "meaningful use"—the criteria hospitals and physicians must meet to collect their cash incentives for installing IT. What will be in these definitions?**

I can't speak to the specific criteria at this point. We are in the middle of writing the regulations, and the initial release is anticipated in December.

**You're giving out $564 million for states to form health-information exchanges among medical providers. Why don't even the most electronically progressive hospitals—including your own Mass General—already share their data?**

There has never been a business case for health-information exchange. As a matter of fact, there has been a negative case: if you give away your information, you may lose it. You may lose the patient.

**You mean lose him or her to a competing hospital.**

That's right.

**The Institute of Medicine has said that between 44,000 and 98,000 Americans die every year from medical errors of various kinds, and that IT can help. Are patients dying because of a lack of information exchange?**

Patients are suffering because necessary information is not available at the point of care. With robust health-information exchange, there can be improved quality of care and improved care coördination. Today, the average 65-year-old with five chronic conditions has 14 doctors and is on multiple medications.

**Do any technological barriers, such as conflicting standards, stand in the way of these hospital exchanges? Would we need to give everyone a national health-care ID to properly merge or reconcile their records?**

No. I think we have almost all the standards we need, but we have to get people to use them. And we can do this without a single health-care ID.

**Why not a single health-care ID? Wouldn't that make things simpler?**

We have a big job ahead of us to achieve widespread adoption and meaningful use of electronic records. We can get to where we want to go without a single health-care ID.

**Was the changeover to electronic records difficult for you personally?**

At some time over the last 10 years, I was basically required to use electronic records. I learned it gradually over time. As I got more capable, I became increasingly convinced of its value in clinical care. It was making me a better physician.

**How, for example?**

A couple of years ago, I saw a patient with a urinary-tract infection. I entered the order for Bactrim [a sulfa drug] on my computerized physician-order-entry system—and a warning came up saying this patient is allergic to sulfa. I am sure in the paper record there was a record of that, but it's often easy to overlook things in a voluminous paper record. That kind of gain, repeated hundreds of thousands of times across the country, can result in real improvements in care. TR

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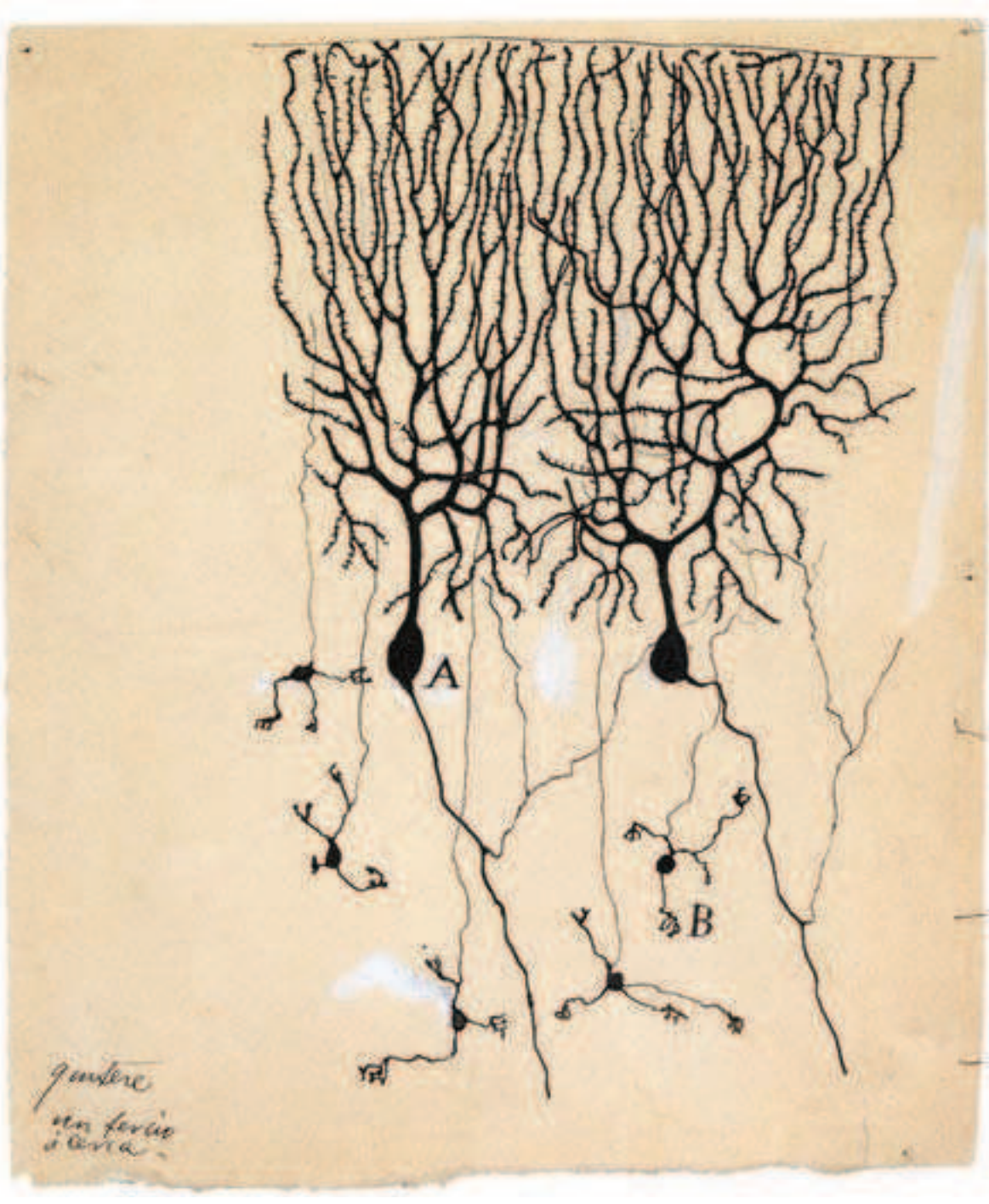
*Photograph by* CHRIS CRISMAN

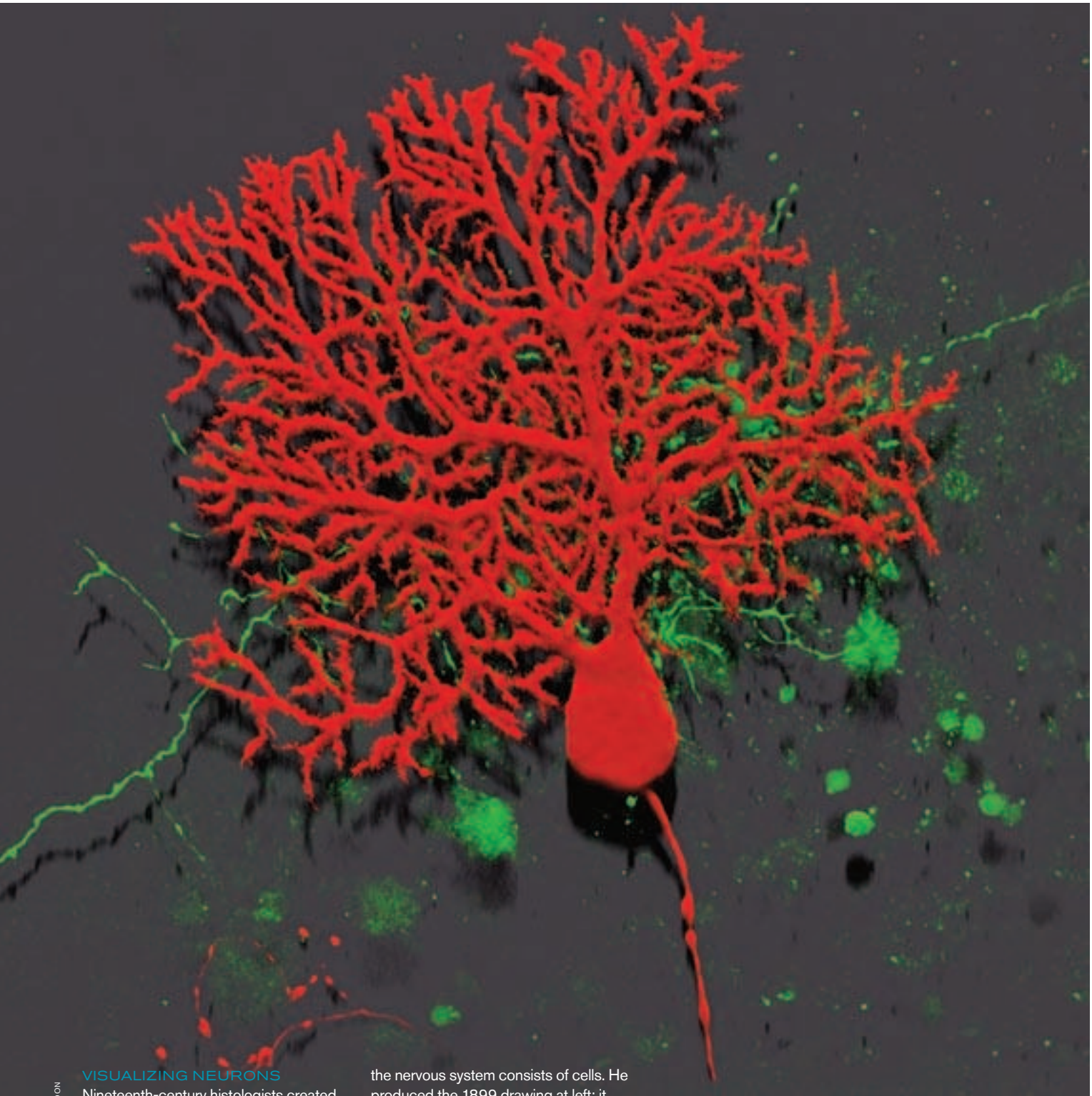



IMAGING

# Time Travel Through the Brain

OVER THE 100-year history of modern neuroscience, the way we think about the brain has evolved with the sophistication of the techniques available to study it. Improvements in microscope design and manufacture, together with the development of cell-staining techniques, afforded neuroscientists their first glimpse at the specialized cells that make up the nervous system. Microscopes with more magnifying power enabled them to probe nerve cells in greater detail, revealing distinct compartments. Newer techniques expose the connections between nerve cells, revealing the complex organization of the brain. By MOHEB COSTANDI

HEREDEROS DE SANTIAGO RAMÓN Y CAJAL

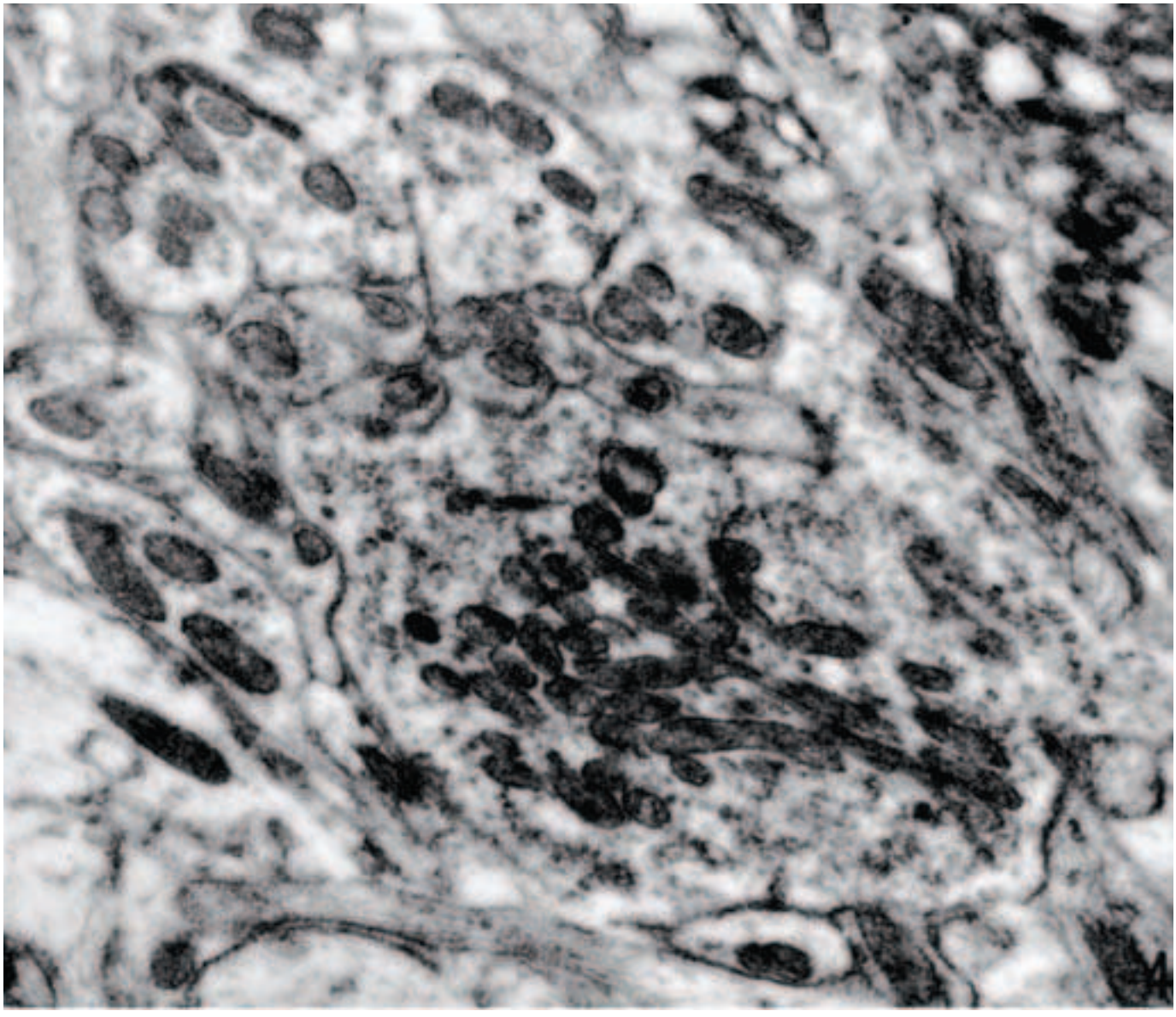


MICHAEL HÄUSSER, UNIVERSITY COLLEGE LONDON

## VISUALIZING NEURONS

Nineteenth-century histologists created some of the first images of nerve cells by chemically stiffening tissue and then immersing it in silver nitrate, randomly staining a small number of cells to make them visible when they were viewed with powerful new light microscopes. The technique revealed the silhouette of the cell body and its network of extensions, and it enabled the great neuroanatomist Santiago Ramón y Cajal to prove that the nervous system consists of cells. He produced the 1899 drawing at left: it shows finely branched Purkinje cells, large neurons in the cerebellum that play an important role in controlling movement.

Fluorescent dyes can now be injected directly into cells to stain the ones a researcher wants to view. The image on this page shows a Purkinje cell in red and a nerve fiber from another cell in green. A single Purkinje cell is connected to hundreds of thousands of these fibers.

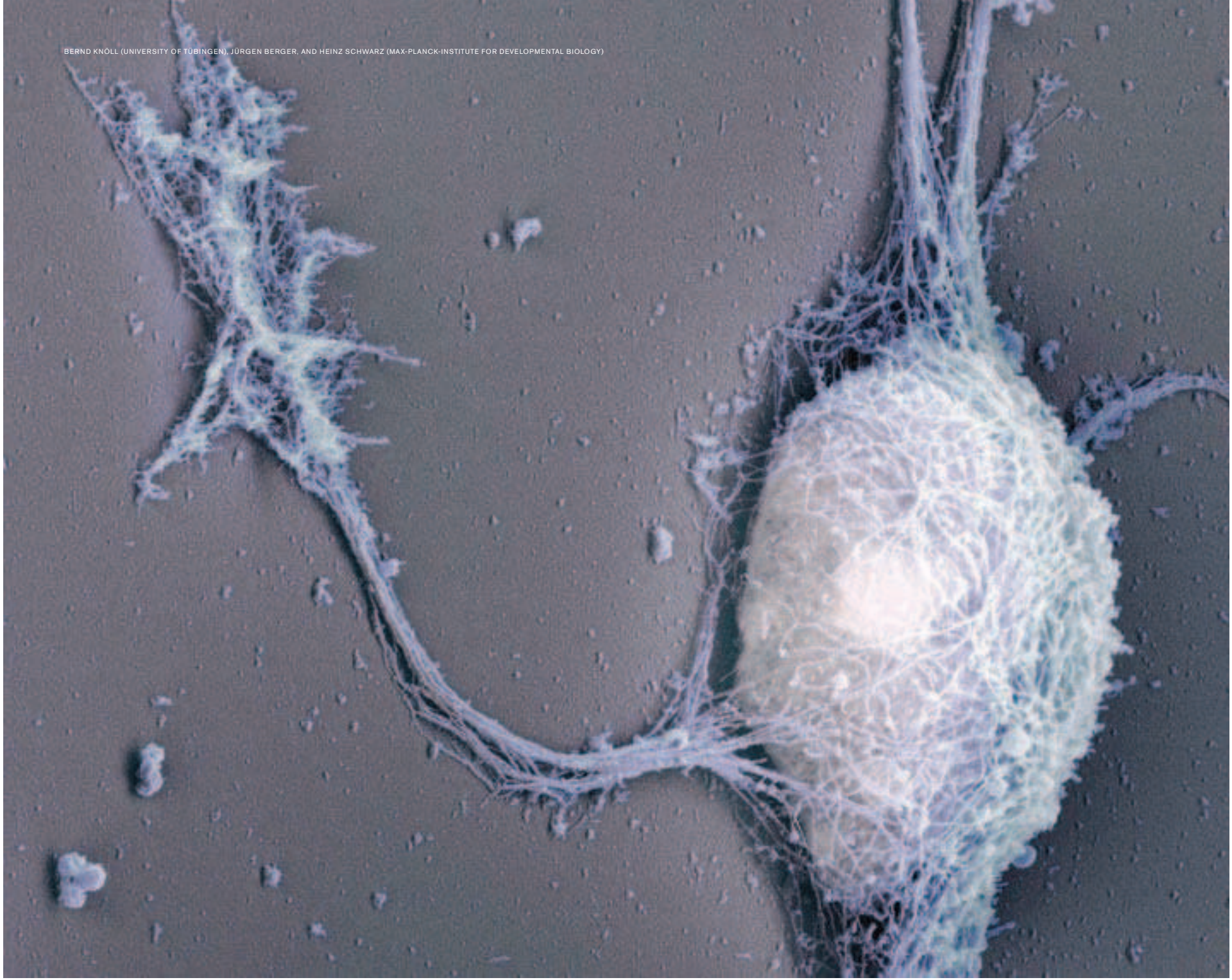


PALAY, 1956. ORIGINALLY PUBLISHED IN THE *JOURNAL OF BIOPHYSICAL AND BIOCHEMICAL CYTOLOGY*, 2: 193-202

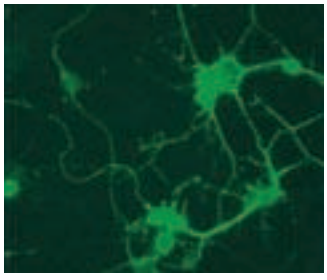
## BEAMING ELECTRONS

Developed in the 1930s, electron microscopes illuminate tissue samples with beams of electrons rather than light, increasing the maximum resolution so that much smaller structures can be distinguished. The image above, of a part of the brain stem that processes auditory information, shows a cluster of nerve-cell connections, magnified 23,900 times. The small, faint circles are synaptic vesicles, which ferry chemical signals between cells.

A newer twist on electron microscopy, developed in the 1980s, can reveal the internal structures of nerve cells. Researchers use a detergent to remove the cell membrane. Platinum and carbon are deposited onto the exposed surfaces to reproduce the cell's interior features as a three-dimensional mold, which is then examined in the microscope. The image at right shows a hippocampal neuron that has been stripped of its membrane to expose the cytoskeleton, a scaffold that regulates the cell's growth and movement.

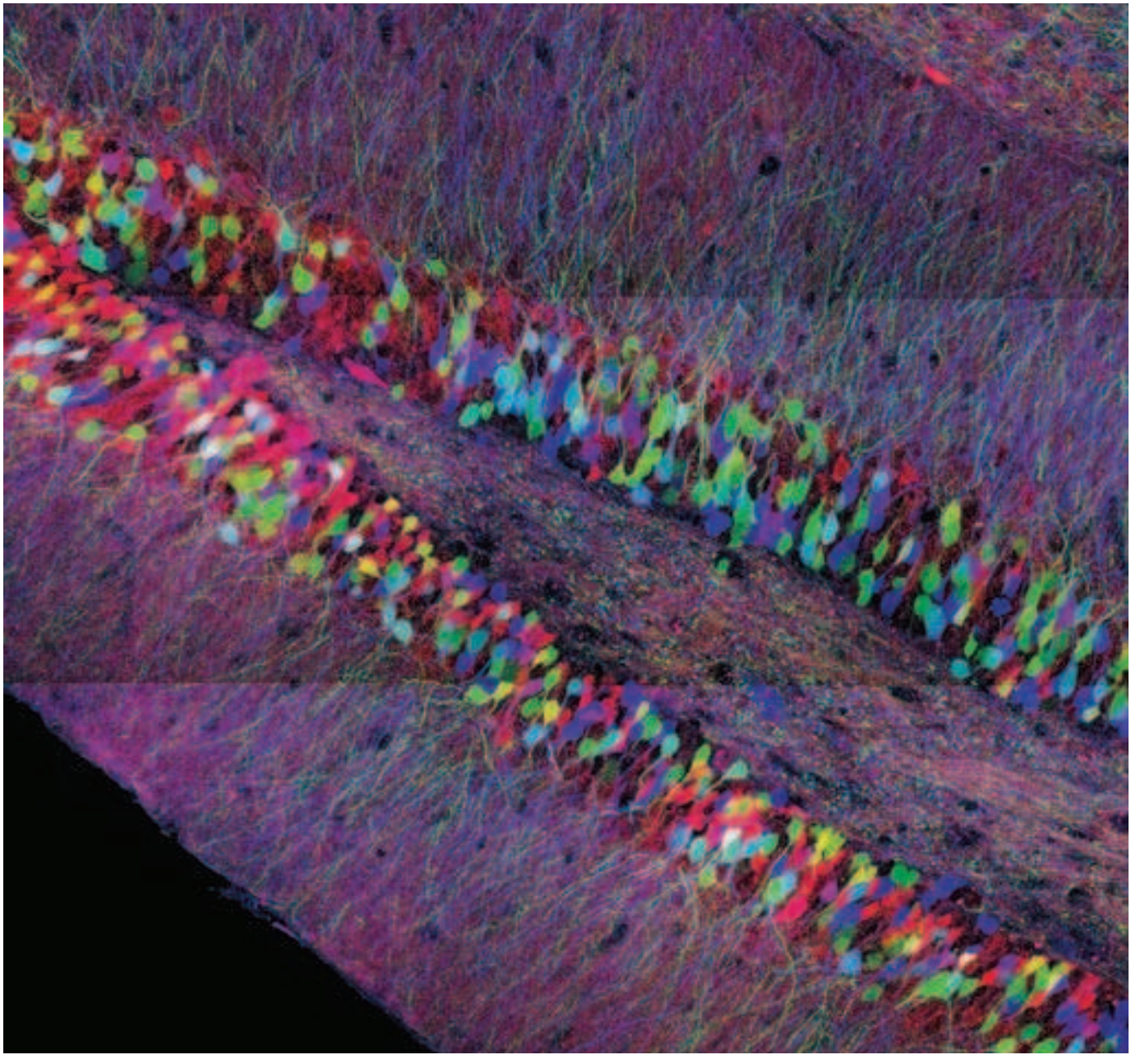


BERND KNÖLL (UNIVERSITY OF TÜBINGEN), JÜRGEN BERGER, AND HEINZ SCHWARZ (MAX-PLANCK-INSTITUTE FOR DEVELOPMENTAL BIOLOGY)

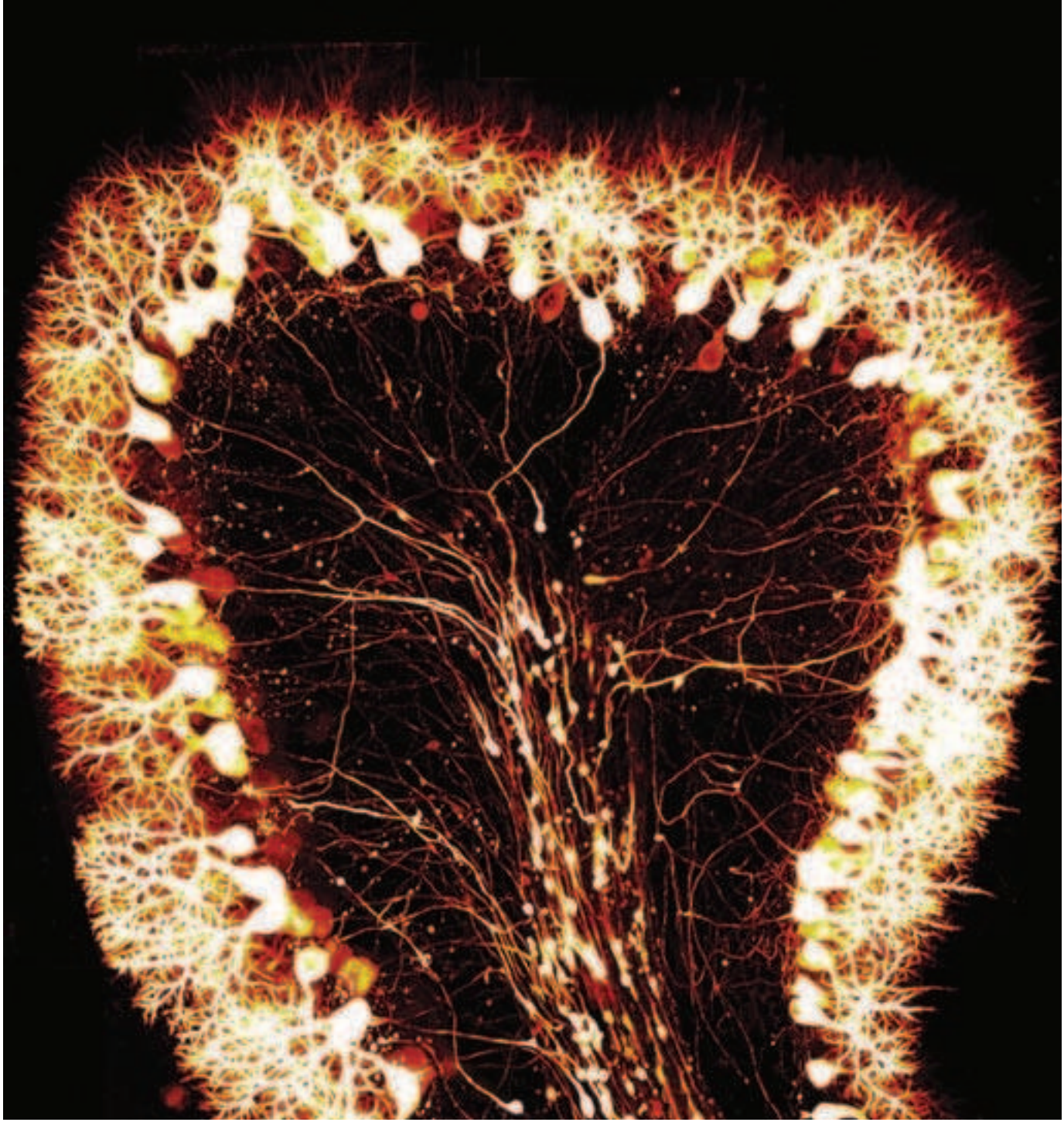


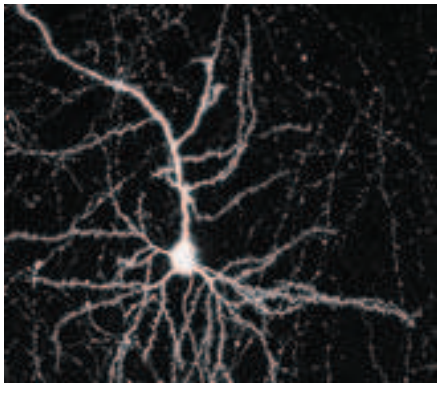
## GLOWING CELLS

In the mid-1990s, researchers began marking specific cells in lab animals by genetically engineering the organisms to incorporate fluorescent proteins (left) found in marine species. Within 10 years, these proteins had been engineered into the cells in more complex ways, enabling researchers to monitor biochemical reactions and track the movements of cellular proteins in real time. Scientists can now label nerve cells in a rainbow of colors. The image below is of a "Brainbow" mouse, which has been engineered so that different nerve cells glow in dozens of hues; it shows the hippocampus, a brain area that is crucial for memory. This technology, developed in 2007, has revealed the connections between cells in remarkable detail.



JEAN LIVET, INSERM (BOTTOM); KOKI MORIYOSHI ET AL., *NEURON*, FEBRUARY 1996 (TOP)

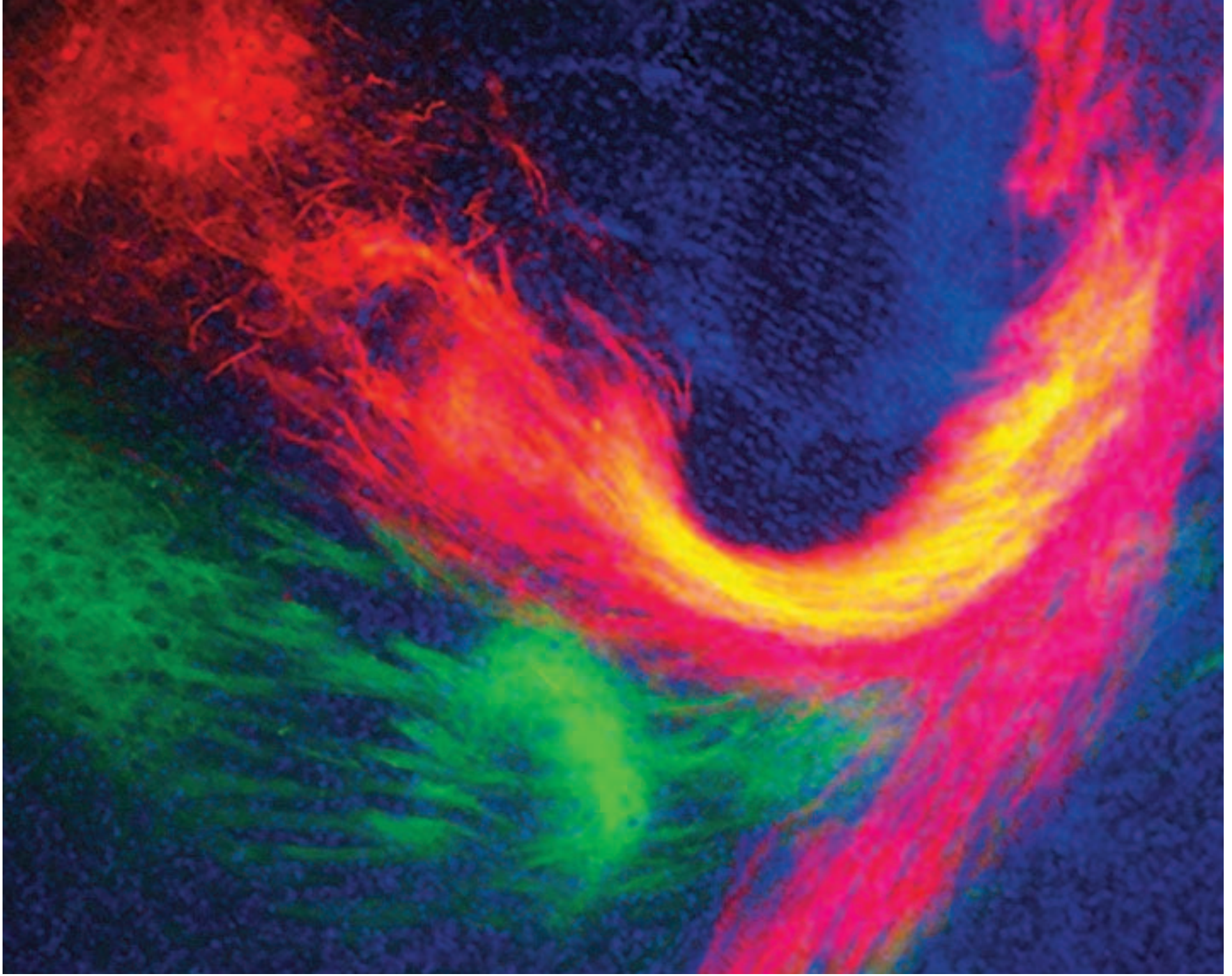


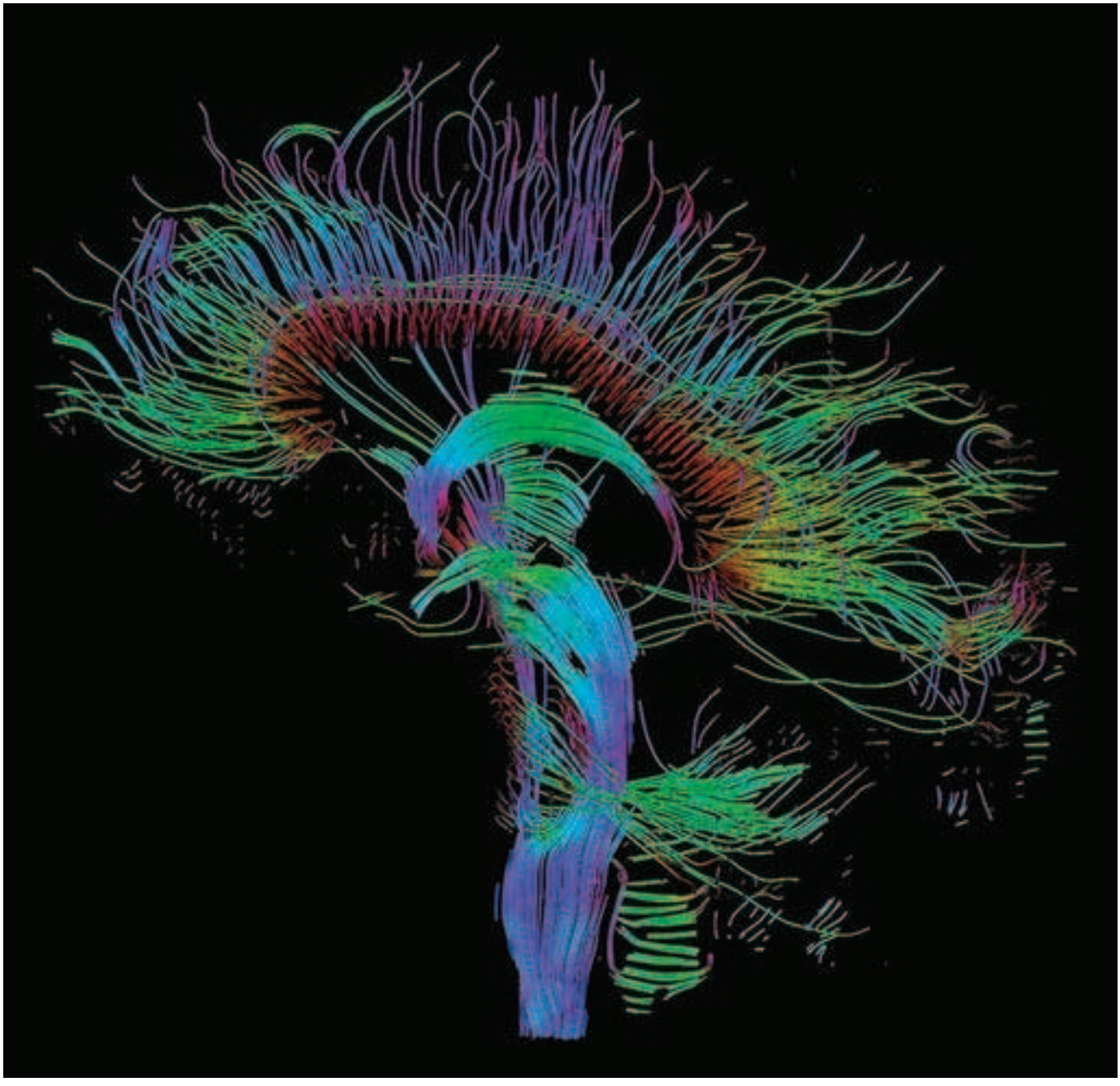


TONY PHAM, BAYLOR COLLEGE OF MEDICINE (BOTTOM); ALANNA WATT AND MICHAEL HÄUSSER, UCL (TOP)

### THE THIRD DIMENSION

Confocal laser microscopy uses focused laser beams to scan tissue. The focused beam reduces the scattered light signal used in conventional microscopes, producing sharper, more detailed images. Light reflected back directly from each point is used to construct a three-dimensional image. This pyramidal neuron from the cortex of a mouse (left) was visualized by scanning the tissue at different depths and superimposing the series of images. In the 1990s, scientists developed a way to further reduce the scatter of light, called two-photon microscopy. This approach, which uses infrared light, can probe deeper into live tissue, producing images like the section of mouse cerebellum shown above.





THOMAS SCHULTZ/UNIVERSITY OF CHICAGO

## TRACING FIBERS

In the 1980s, scientists developed fluorescent dyes to help them examine the long, thin extensions of neurons that carry information between these cells. Injected directly into the brain, the dye is incorporated into the cell membrane and transported along it, revealing the route of the nerve fiber. The image at left highlights the long-range connections between sensory areas of a mouse's cerebral cortex and thalamus, often called the brain's relay station. Fibers from the primary visual cortex are shown in red, while fibers from the primary somatosensory cortex, which processes bodily sensations, are shown in green. Today, scientists can safely examine these connections in a living human brain using a variation of magnetic resonance imaging (MRI) called diffusion tensor imaging. This technique, developed in the 1990s, infers the location of nerve fibers by tracking water molecules in the brain as they move along them. The image above shows fibers radiating from the thalamus in a human brain.

www See more images of the brain at: **technologyreview.com/brainpics**

# Prescription: Networking

## A new urban network suggests how technology could remake health care.

*By* DAVID TALBOT

A crow flying from Vera Sinue's apartment in Boston's Roxbury neighborhood to her job as an insurance representative near the Charles River in Brighton would skirt the edge of the Longwood Medical Area, a district of medical institutions including Brigham and Women's Hospital, Beth Israel Deaconess Medical Center, Children's Hospital, the Dana-Farber Cancer Institute, and Harvard Medical School. These institutions are among the nation's most respected. They supplied some of the experts now leading the Obama administration's effort to reform the nation's health-care system.

Yet it's lucky for Sinue that when she began vomiting uncontrollably one day last August, she didn't end up at any of the Longwood hospitals. Sinue, who is 35, gets her routine medical care at the Codman Square Health Center, in the heart of the low-income neighborhood of Dorchester. Her Codman Square records would not have been accessible to any of the Longwood emergency departments. While Boston's medical institutions generally lead the nation in using advanced information technology for their own networks of physicians and satellite health centers (and the Longwood hospitals were early adopters), the networks don't connect with one another to share data about patients' medical histories and needs.

As it happened, Sinue went to Boston Medical Center, in the city's South End, just a few weeks after Codman's records became part of a network linking BMC with 10 community health centers. BMC, the teaching affiliate of the Boston University School of Medicine, runs New England's largest trauma center and busiest free-care service. But it's the links with the neighborhood health centers that are most remarkable. The health centers aren't owned by BMC, so there were plenty of institutional barriers to their sharing patient data. And what this group of institutions has started doing to break down those barriers is an example of what the entire U.S. health-care system needs to do to make the best use of information technology. "In terms of a hospital taking the initiative to do what they have done—link together, using national standards, a set of individual physician-based medical records—it's not all that common," says John Halamka, CIO of Harvard Medical School and Beth Israel Deaconess Medical Center, who serves on regional and national bodies advancing health IT. "BMC is a leader in health-care information exchange." The effort is especially significant because BMC serves so many low-income patients—who suffer disproportionately from chronic diseases and often have fragmented histories of care, making it all the more important for information to be shared among care providers.

Inside the BMC emergency room, Sinue's vomiting did not stop. The attending physician, Aneesh Narang, was understandably worried. He asked if this had happened before; she muttered that it had happened only in childhood. A sudden and acute bout of vomiting might indicate appendicitis or ischemic bowel disease (the death of intestinal tissue), either of which would require speedy surgery. In the absence of more information, most emergency-room doctors would order a CT scan (at least $2,100), and possibly an abdominal ultrasound (another $500), to see what was going on. But Narang called up the electronic records from Codman and found lab data and physicians' notes that spelled out her allergies, medications, and history of medical problems.

These records were certainly not cutting-edge medical IT—no genomic data, not even any images. But they would make a big difference. Narang quickly saw that Sinue hadn't told the full story. In fact, vomiting was a chronic issue; it topped her list of medical

GUIDO VITTI

RECORD SAVE In the Boston Medical Center's emergency department, Vera Sinue might have been subjected to a CT scan and other tests. But new electronic medical links with her community health center reassured doctors that her mysterious vomiting was not an acute issue.

problems. At one point she'd even had an endoscopic procedure to examine her digestive tract for signs of ulcers or other abnormalities. It's not clear why Sinue hadn't disclosed this information. (She later told me she might have forgotten.) Whether caused by stress, cultural differences, or language barriers, such miscommunication "is not really that surprising—we get it all the time," says Andrew Ulrich, an emergency room physician who is also vice-chair of BMC's emergency department. "You'd be amazed what people don't remember. But this reassured us that this was not an acute problem." Doctors knew they could skip the CT scan and the ultrasound, thus saving time and money—and sparing Sinue a dose of radiation from the CT test. She was treated with anti-nausea medication and intravenous fluids. Once the crisis passed, a talk with a physician revealed that Sinue was distraught over a personal issue. When the subject came up, she was overcome with nausea. She got a referral for what she probably needed most: counseling.

### "WORKING IN THE DARK"

Information technology—used properly and broadly—could help remake the U.S. health-care system. In 2006, the National Academies' Institute of Medicine (IOM) called for a nationwide health-IT system to help prevent the drug errors that it said injure 1.5 million Americans every year. Electronic prescriptions, the organization argued, could eliminate problems caused by hard-to-read handwriting, and they could be incorporated into systems that would automatically catch physicians' mistakes. The IOM had previously called for "electronic databases and interfaces" in a 1999 report finding that 44,000 to 98,000 Americans die annually from medical errors of all kinds. Using such technology, it found, could not only prevent fatal mistakes but also ensure that patients aren't subjected to redundant tests, that they get cancer screenings in time, and that they manage chronic diseases more effectively. Yet progress has been painfully slow: though the number of physicians using electronic records has inched up over the past decade, 83 percent of them still use paper records today.

Besides improving or even saving patients' lives, electronic records can potentially save money by reducing hospitalizations and eliminating unnecessary procedures, as they did for Sinue. In 2005, a think tank run by Partners HealthCare, the organization formed by Massachusetts General and Brigham and Women's Hospitals (whose own network of hospitals and physicians uses some of the most advanced electronic-records applications in the nation), estimated that introducing this technology would save $78 billion nationwide. Though subsequent analyses have questioned that figure, nobody disagrees that the $2.3 trillion annual U.S. health-care bill includes staggering levels of waste. "If you ask how much in total medical spending there is in the country that doesn't need to happen—providing absolutely no clinical benefit—the answer is probably about $700 billion a year," says David Cutler, an economist at Harvard University and a former health-care advisor to President Obama. "Health-care IT is a fundamental part of getting rid of that. It is not the only important thing. But without information, you'll never get rid of it."

"If you ask how much in total medical spending there is in the country that doesn't need to happen—providing absolutely no clinical benefit—the answer is probably $700 billion a year. Health-care IT is a fundamental part of getting rid of that."

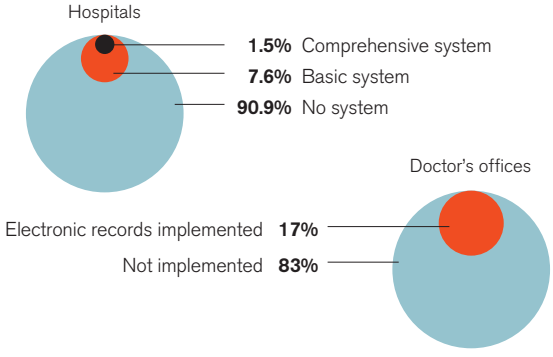
To promote effective use of such technology, Congress included huge incentives for health-IT purchases in the stimulus legislation passed earlier this year *(see "Can Technology Save the Economy?" May/June 2009 and at technologyreview.com)*. Physicians and hospitals can collect cash—as much as $44,000 over five years for individual doctors, and millions of dollars for hospitals—if they document not only the adoption of electronic records but the "meaningful use" of that technology before 2012. "Meaningful use" is now being defined in detail by the Office of the National Coördinator for Health IT, led by David Blumenthal, a physician and former director of Partners HealthCare's Institute for Health Policy *(see Q&A, p. 24)*. Doctors who don't meet that standard before 2015 will face financial penalties: 1 percent taken from their Medicare fees in the first year, 2 percent in the second, and 3 percent in the third and subsequent years.

The ultimate goal: a privacy-protected Nationwide Health Information Network that would allow medical institutions across the country to exchange patient records. Hardly any of them coöperate in this way today; sharing electronic records *between* hospitals is a huge step beyond using them *within* hospitals. While a few robust regional networks have been running for years, they remain geographically limited. "As with electronic medical records, there are a few showcase places, and then there's the whole rest of the world," says Bonnie Kaplan, a lecturer in medical informatics at the Yale School of Medicine.

The public-health advantages of an integrated network could be tremendous: huge sets of regional and national data could be analyzed to help researchers to discern optimal treatment strategies, unearth dangerous drug side effects, and give early warning of epidemics and other large-scale problems. But lower-income patients might benefit more directly than any other group. They are more likely to have bounced around among various providers;

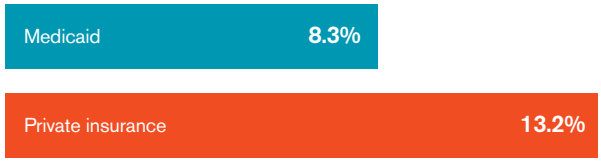
## ELECTRONIC RECORDS: LIGHTLY USED BUT PROMISING

**U.S. adoption of electronic medical records is low ...**



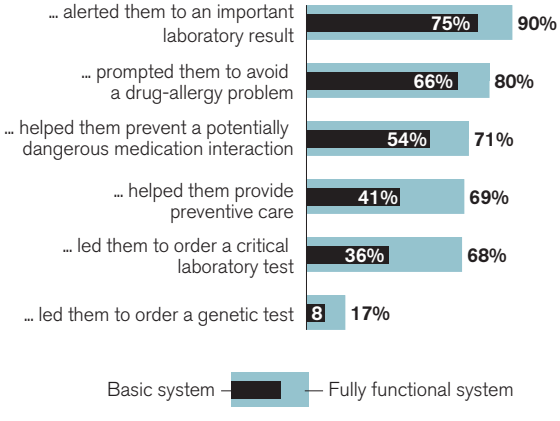

**... especially for low-income U.S. patients.**

PERCENT OF PATIENTS' PRIMARY-CARE PHYSICIANS USING ELECTRONIC RECORDS, BY INSURANCE SOURCE




**But where such systems are used, doctors see benefits.**

DOCTORS WHO SAID ELECTRONIC RECORDS HAD ...




*Sources: New England Journal of Medicine (adoption rates and physician survey); Journal of Health Care for the Poor and Underserved*

TOMMY McCALL

they suffer disproportionately from chronic health problems such as diabetes, heart disease, and asthma; and they often end up getting primary care at emergency rooms. "Our patients, probably more than other patients, are not as able to advocate for themselves," says Meg Aranow, the vice president and CIO of BMC. "They may have language issues. And we have cultural barriers, such that people are more or less comfortable talking to another gender or someone who is perceived to be of a different class. There are a ton of communication issues that burden our practice." Even when such issues don't arise, doctors or nurses often need records from other hospitals in order to give patients proper care. And today that generally means phoning records clerks and waiting for faxes to come through—a process that can take hours or days.

Nobody understands that problem better than Robert Gamble, a nurse practitioner with Health Care for the Homeless, one of the health centers now linked with BMC. His clients shuttle between shelters, transitional lodging at motels, and the streets. Gamble recalls a 28-year-old woman from Worcester, MA, obese and suffering from high blood pressure, who had been assigned temporary housing with her two-year-old son at a motel in Marshfield, 50 kilometers south of Boston. Gamble was traveling back and forth to see her, and trying to arrange medications for her—and immunizations for her son—through phone calls to her doctor in Worcester, 120 kilometers from the motel. "I'm used to working in the dark, just working from the issues that are presented in front of me," he says. "It will be great to get more history, medication lists, and other background stuff."

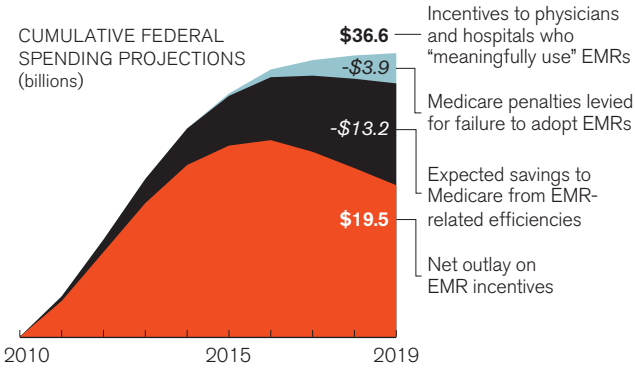
### LONG SLOG

It's easy to understand why BMC wanted better connections with the community health centers, many of which serve poor and minority neighborhoods. Their patients often come to BMC for specialist visits or emergencies. But the hospital couldn't build those connections until the smaller institutions computerized their records, and community health centers—which number about 1,200 in the United States—are particularly hard-pressed to invest in IT on their own, says Robert Miller, a health economist at the University of California, San Francisco. The Boston project, which originally targeted 15 health centers serving 206,000 patients, became possible only when an anonymous donor contributed $5.5 million in 2001.

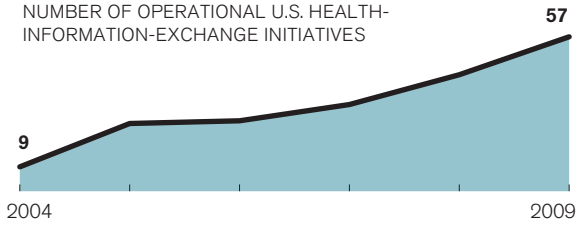
The first three years were consumed by the effort to set up electronic records at the health centers and persuade staff to use them. "For a long time during the transition, the doctors at the health centers refused to let go of the paper record," says Francis Doyle, executive director of Boston HealthNet, which runs the network. Once that hurdle was overcome, the first links were forged. Beginning in 2005, BMC doctors were able to log in and look up records in the databases of the individual health centers, though a separate password and user ID was still needed for each one. But the

## BOOSTER SHOT FOR HEALTH IT

**Stimulus funds will turbocharge adoption of electronic medical records (EMRs).**




**The number of local organizations sharing electronic health information is already rising.**




*Sources: Congressional Budget Office (stimulus); eHealth Initiative*

doctors and nurses at the health centers came to realize that these new links were of limited use unless all the centers and BMC networked their data to create a single patient record available to any clinician anywhere in the network. It would take $1.25 million in two grants from the U.S. Health Resources and Services Administration to create this truly integrated network—one that so far covers 10 health centers, not all 15 originally envisioned. (The other five will be added in the next year or two.)

To create a single, searchable system, BMC and the health centers needed to reliably match records for the patients in their respective databases. They did it with software from GE, one of several major health-IT vendors. The technology looks at birth dates, addresses, race, and other identifiers to distinguish patients with similar names and, conversely, to determine when records containing different addresses or differently spelled names actually refer to the same person. It creates a master index, but the actual patient data stays at the individual health centers. When a doctor logs in at BMC, the software pulls out the latest information from all sources. And a doctor needs to remember only one user ID and password.

The BMC network went live just this summer, so the hospital has not yet formally analyzed its impact. But anecdotes like the one about Vera Sinue have been trickling in. And after just two weeks, Dan Newman, BMC's chief medical-information officer, stumbled across one of the system's ancillary benefits. Newman had been treating a man in his 60s for chronic back pain. "I had had problems with this patient in the past," he says. "He would show up every single month for his medication but wouldn't go for any tests to work up the cause of his pain." Sure enough, the system showed that the patient had visited several of the health centers: he was doctor-shopping to obtain prescriptions for painkillers. "They had Percocet on the medication list and were writing him for other drugs, too," Newman says. He adds that the system has unmasked other patients doing the same thing. And data mining from eight of the connected health centers has already begun in an effort to improve patient care. A particular focus is on the chronic health problems afflicting the network's patients. (To pick just one of many sad national statistics, African-American diabetics are 2.3 times as likely as white diabetics to suffer preventable complications that require amputation of a foot.) The eight health centers serve more than 70,000 adult patients and have begun tracking seven indicators of diabetes or heart disease—which affect more than 5,000 of them—while working on outreach strategies to help them manage their health. (More than half the patients in the network receive care at more than one of its facilities, so sharing the data is crucial.) The neighborhood health centers have also overhauled their notoriously inefficient process for managing referrals to BMC specialists. Previously, this process relied on the patients themselves, with uneven results. "We'd end up with patients sitting in the cardiologist's office, and the cardiologist would ask, 'Why are you here?' and the patient would respond, 'I have no idea,'" Newman says. "Some of them would say, 'I don't even know what my doctor's name is.'" Now the specialists can call up the complete record. And with fewer repeated appointments, everybody is wasting less time.

Despite all this, a visit to BMC's emergency room provides a reminder that electronic records, even those shared within an innovative hospital network, are of limited use unless the data is shared more widely across the health-care system. On the August day when Sinue came to BMC, only 164 of the 366 patients seen in its emergency room had previously visited that hospital or any of the 10 health centers. The rest had no records in the system: 77 said they had primary-care physicians outside the network, and 125 said they had no such provider at all. This latter group included Joycelyn Jobson, a 60-year-old woman who arrived complaining of pain in the left side of her abdomen. The doctors performed an electrocardiogram (EKG) and noted a slight abnormality in her

TOMMY McCALL

Smarter technology for a Smarter Planet:

# Is your information withholding information?

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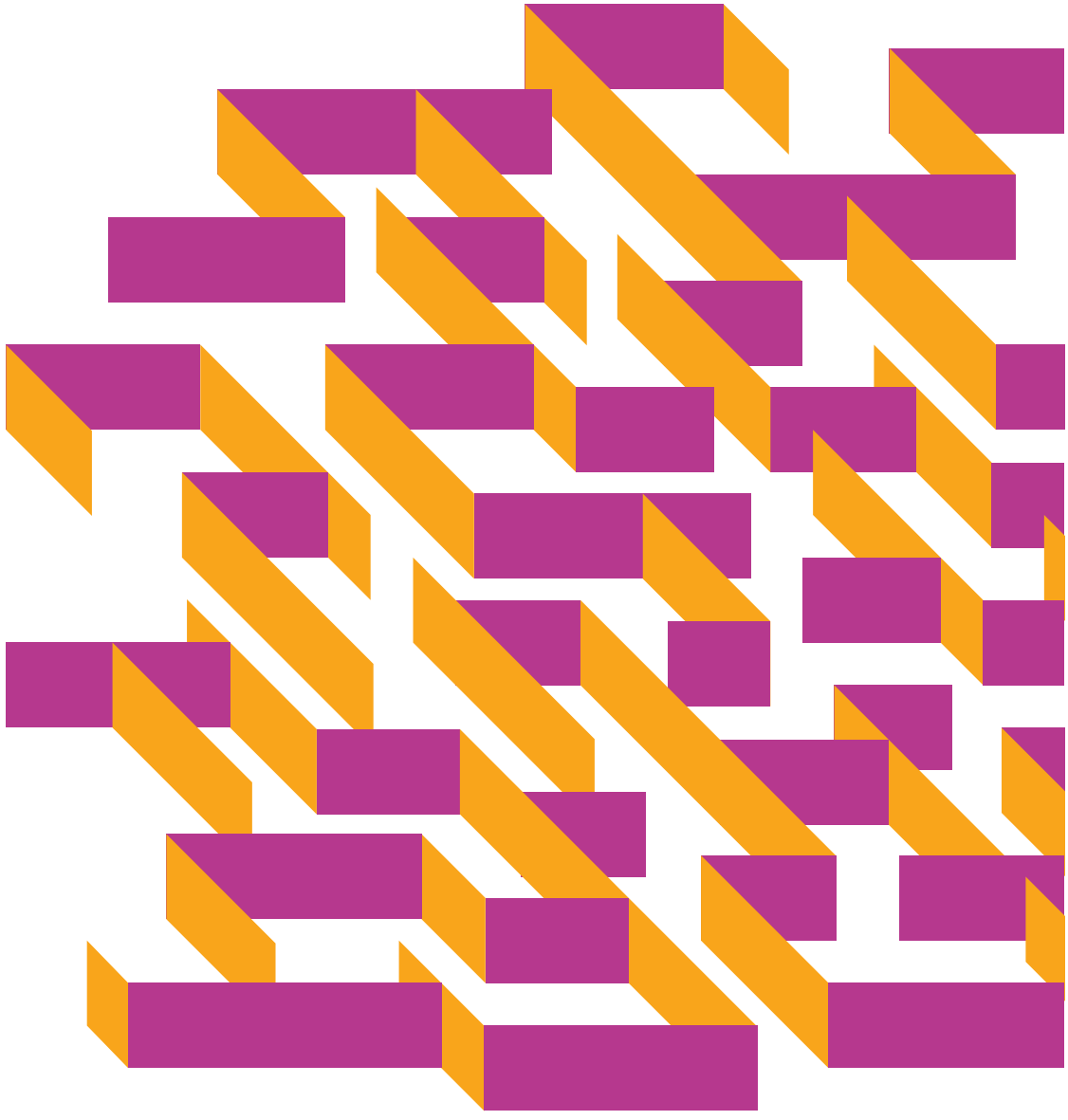


heart rhythm. This was a red flag: it could have meant she was in the early stages of a heart attack. Or it could have been nothing—perhaps the vestiges of a cardiac event years earlier.

I went up to Jobson's room. There, a resident, Jessica Eng, was trying to tease out more information.

"What's wrong?" Eng wanted to know.

"This pain ... bad feeling," Jobson replied. "Won't leave me alone."

"How long?"

"Long time. Long time now."

"What kind of treatment have you had for this?"

"Nothing."

"Have they looked at it with scans or ultrasound?"

"Yes."

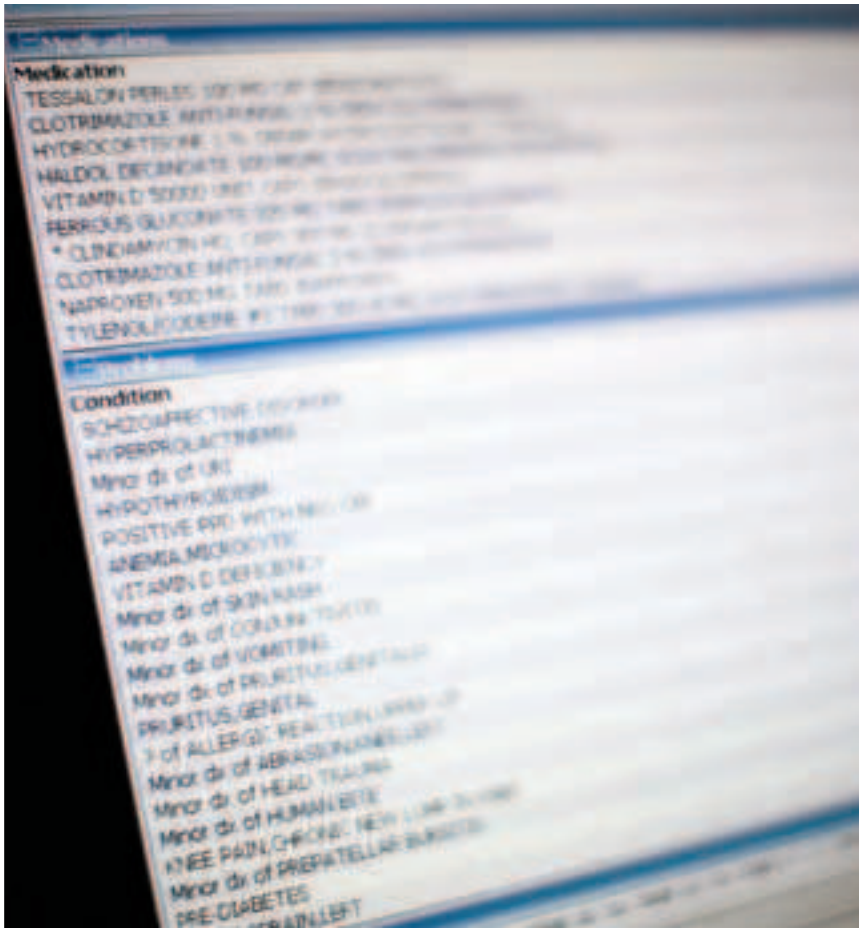
"Have they ever had a camera inside?"

"No."

It wasn't clear whether real communication was actually happening, or whether Jobson even had an emergency; at one point, she told me she'd had the pain for 20 years. Doctors were hopeful when she said she'd previously been to the Codman Square Health Center. (She lives in Jamaica, where she and her husband raise yams and pigs on a small farm, but regularly visits her son and grandchildren in Boston's Mattapan neighborhood.) Yet the database revealed no hits. And so an expensive medical odyssey began. She was admitted for observation and hooked up to machines that monitored her vital signs. Nurses checked blood pressure in both arms; a difference was noted. This can be harmless, or it can signify a life-threatening tear in the thoracic aorta. So the nurses wheeled Jobson in for a CT scan. No tear was found. But a radiologist examining the scan saw nodules in Jobson's lungs. Though the nodules probably indicated infection rather than cancer, the discovery meant ordering another CT scan in three to six months to rule out a malignancy.

DATA DOCTOR Andrew Ulrich, an emergency physician at Boston Medical Center (left and far right), says miscommunication between doctors and patients is commonplace, and patients often don't remember what medications they're on. BMC clinicians can now consult detailed patient records linked to primary-care physicians at Boston-area community health centers (center). Such links can help resolve medical mysteries.

PORTER GIFFORD

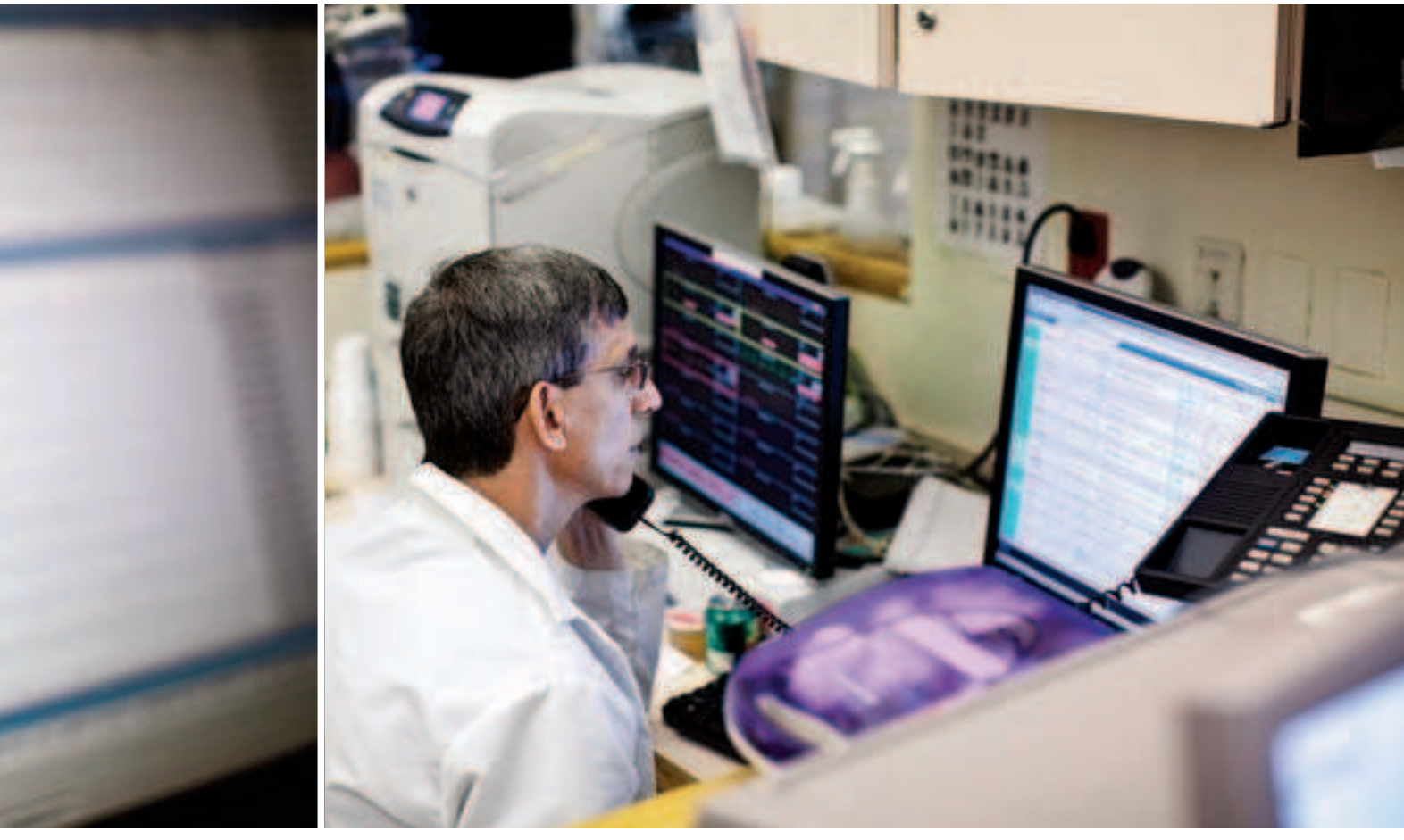



"The cardiologist would ask, 'Why are you here?' and the patient would respond, 'I have no idea,'" an official at BMC says. Now, specialists there can call up patients' complete electronic records from local health centers.

Plausibly, all of this could have been avoided if the doctors been able to find an earlier EKG showing that her cardiac abnormality was preëxisting. In the end, the doctors found nothing wrong. Three days later, Jobson was discharged. Her care probably cost something in the neighborhood of $15,000—surely a piece of the $700 billion in spending that the economist David Cutler was talking about. And doctors at BMC say the story is typical of patients for whom no records can be found. Vague complaints result in a fusillade of defensive and probably needless tests and treatments—a situation that is unlikely to change unless doctors and hospitals all around the country can share and analyze data electronically.

### BALKANIZED CAREGIVING

What will it take to stitch together all the health-care providers in greater Boston, let alone the entire United States? Linking disparate facilities is technically possible now, but the fact that it took BMC eight years just to make connections with 10 health centers shows how hard the process can be. Hospitals are businesses, after all, and don't want to lose patients to competitors. Nor do they want to violate patient confidentiality, a risk that can increase as information is shared beyond a hospital's walls. "What's in it for the hospital to give up their data? What is the incentive?" says Larry Nathanson, director of emergency-medicine informatics at Beth Israel Deaconess Medical Center in Boston. "Right now, under the current model, there is a lot of risk involved if you are going to share your data. There is considerable risk, and there is little benefit. Except maybe a 'herd benefit'—if you do it for me, I do it for you." Beth Israel uses software developed by Nathanson



TB-FREE Colleen Clougherty needed a medical checkup in the Boston Medical Center emergency department before entering a detox facility. An electronic record made reference to a positive tuberculosis test 14 years ago but didn't say whether she was now TB-free. Doctors were poised to order a chest x-ray until a nurse made telephone calls to confirm that she was healthy. Sharing electronic records more widely among providers could spare patients from needless tests and radiation—and save costs.

to manage care in its emergency department, but the technology can't access records at other hospitals in the area.

Massachusetts health-care executives have long discussed wider information sharing among clinical facilities, and they've even hammered out the technical prerequisites. But in Boston as elsewhere, medical institutions are still inclined to spend their IT budgets on their individual needs, concedes John Glaser, vice president and CIO of Partners HealthCare. (Glaser is now on loan four days a week to the Office of the National Coördinator of Health IT, where he is a senior advisor to David Blumenthal.) "From a research perspective, there is a lot of collaboration," he says. "But a patient who moves from BMC to Brigham—does the data move with them? No. That is typical across the country. If you sit at a board meeting, whether at Brigham or Beth Israel Deaconess or BMC, and say, 'All right, we have $10 million in capital funds and $40 million worth of requests,' and one is to improve an IT system for nursing care, and another is to connect electronically with the Lahey Clinic, the one for the nurses is going to win every day."

That should start to change as states begin receiving their share of the $564 million that Blumenthal has designated for jump-starting statewide and regional health-information networks. And the forthcoming "meaningful use" definitions are likely to include additional incentives for networking at the state and, eventually, national levels. Executives from most hospitals in eastern Massachusetts plan to start sharing discharge summaries (as patient records of hospital stays are called), something a few hospitals are already doing. And several pilot projects for data exchange are under way.

A national network of electronic medical records would not just promote greater efficiency and more consistent patient care; it could also give rise to unexpected insights. Consider the case of the onetime blockbuster anti-inflammatory drug Vioxx. It was a 2004 analysis of the electronic medical records of 1.4 million patients in the Kaiser Permanente health-maintenance organization that showed that users of Vioxx—on the market since 1999—were twice as likely to suffer heart attacks or strokes as people

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PORTER GIFFORD

who took a rival drug, Celebrex. Later, Glaser says, Partners HealthCare looked at its own network data and found a similar pattern. "When you look at this data, your reaction is 'Holy shit, we could have seen this in 2001!'" he says. "You can see the signal. The key question is: if we look at more and more of this data, can you see these kinds of signals much earlier?"

But those benefits are abstractions in relation to clinicians' daily struggle to make sense of isolated scraps of data on individual patients. Consider the hot August night when it fell to Dona Petrozzi, a psychiatric nurse in BMC's emergency department, to line up the proper care for a Dorchester narcotics addict named Colleen Clougherty, who'd called for an ambulance after suffering from hallucinations. Clougherty wound up in a special guarded wing reserved for psychiatric emergencies. Her room had no furnishings other than an examining table bolted to the floor. Clougherty sat on its edge, clutching a blue stuffed bunny she'd brought. Gaunt, with slicked-back blond hair, she wore gold hoop earrings and had a large tattoo of a leprechaun on her arm. "I had sensations. I could feel a lot of things—a lot of weird, creepy things," she explained to me. "Like crabs were crawling on your toes, or like a slug was stuck to the side of your face, or like a spider was blowing on your head."

Clougherty needed her medical condition checked before she could be sent to an inpatient psychiatric and detox facility. But that wasn't easy to do. Although she gets her health care at the Neponset Health Center in Dorchester, some of her medical records were held in a special Boston-area computer system called BEST, for Boston Emergency Services Team, which was set up by BMC and mental-health agencies to keep track of psychiatric patients' medications, hospitalizations, and histories. Petrozzi looked up Clougherty's file. She saw a worrisome note from 14 years before: at the time, Clougherty had tested positive for tuberculosis. Since BEST is not integrated with the Neponset Health Center (and neither is BMC, though that's in the works), Petrozzi had no easy way to see whether her patient might be sick and contagious. Without clarity in the record, doctors would have had to order a chest x-ray to rule out any signs of TB before releasing her.

Fortunately, Petrozzi and her colleagues were able to reach a Neponset staffer by telephone and confirm that Clougherty had had a clear x-ray within the previous year. But such improvisation is hardly a substitute for making electronic records readily available to the clinicians who need them. "Ideally, inpatient hospitalization admittance and discharge is supposed to provide a seamless transition from one milieu to the next," Petrozzi said as we sat in her tiny, windowless office. On the wall hung a few reminders of other crises she deals with. A photocopied sheet of paper said, in bold letters: *Please report all deaths to the New England Organ Bank—800-446-6362.* She told me, "If you don't have information—and it's true of any level of care, but particularly in psychiatry—you are interfering in some way with the patient's physical and mental well-being. You don't want that to happen."

The rancorous political debate over health-care reform tends to mask this kind of commonsense—and widely shared—understanding about the value of basic access to information. "The good thing about information is that most everyone can be in favor of it," says Cutler, who recently coauthored a bipartisan report to Congress on the importance of properly deployed information technology in reforming health care. (It was also signed by a scholar at the conservative American Enterprise Institute.) "And if you look at the difference between the last time we looked at health-care reform, in the 1990s, and now, the single most important change is that the IT has changed. What everyone believes—not just left of center, not just right of center, but everyone—is that is now is the moment to seize that and really put it to work." TR

DAVID TALBOT IS *TECHNOLOGY REVIEW*'S CHIEF CORRESPONDENT.

DEEP DRILLING At Range Resources' site in Washington County, PA, a specially designed rig is used to drill more than a thousand meters down and gradually turn 90° to follow the gas-rich shale deposit. The rig will drill half a dozen wells at the site. Beside it is a pond holding debris and mud from a well.

# Natural Gas Changes the Energy Map

## Vast amounts of the clean-burning fossil fuel have been discovered in shale deposits, setting off a gas rush. But how it will affect our energy use is still uncertain.

*By* DAVID ROTMAN

The first sign that there's something unusual about the flat black rocks strewn across the shore of Lake Erie comes when Gary Lash smashes two of them together. They break easily and fall into shards that give off the faint odor of hydrocarbons, similar to the smell of kerosene. But for Lash, a geologist and professor at nearby SUNY Fredonia, smashing the rocks is a simple trick designed to catch the attention of a visitor. The black outcroppings that protrude from the nearby bluff onto the narrow beach are what really interest him.

To Lash's expert eyes, the wide band of black shale, which runs roughly parallel to the beach, reveals hundreds of millions of years of geological history. The shale formed more than 350 million years ago when organic muck settled at the bottom of the shallow sea that covered much of what is now the eastern United States; it was once buried more than two kilometers underground but has gradually risen to the surface. Now, the exposed rock shows telltale patterns of breaks and splits. "We've demonstrated that these fractures could only have formed as a result of the generation of hydrocarbons," says Lash.

This formation is the edge of vast deposits of black shale that stretch under tens of millions of acres below western New York, much of western and northern Pennsylvania, and parts of Ohio, West Virginia, Maryland, and Kentucky. The oldest and deepest layer is called the Marcellus shale, and if geologists like Lash are correct, it holds enough natural gas to help change the way the United States uses energy for decades to come.

Experts now believe that the country has far more natural gas at its disposal than anyone thought three or four years ago. The revised estimates are largely due to advanced drilling techniques that make it economically feasible to extract the fuel from shale. And while the Marcellus is the most recently discovered and possibly the largest shale-gas deposit, others are scattered throughout the country. The U.S. consumes about 23 trillion cubic feet (TCF) of natural gas a year, according to the Department of Energy's Energy Information Agency (EIA). The Potential Gas Committee (PGC), an organization headquartered at the Colorado School of Mines, put the country's potential natural-gas resources at 1,836 TCF in a biennial assessment released in June. That's 39 percent higher than its estimate of two years earlier. Add to that the 238 TCF that the EIA has calculated in "proved reserves" (the gas that can be produced given existing economic conditions) and the PGC pegs the future supply at 2,074 TCF. In other words, there is enough natural gas to supply the country for 90 years at current consumption rates. Even if we used natural gas to totally replace coal in generating electricity, domestic supplies would last for 50 years.

*Photographs by* ROY RITCHIE

PASTORAL SCENE Drilling for natural gas in the Marcellus shale is under way in rural areas of southwestern Pennsylvania and other parts of the state. Advocates argue that the process has only a marginal environmental impact and, once the drilling is completed and the well is producing, leaves a small footprint on the landscape (right). Critics worry that the chemicals and huge amounts of water required to stimulate the wells will damage the surrounding areas.

Almost all the newfound resources are in shale deposits, which are now estimated to contain 616 TCF of recoverable gas, says John Curtis, a professor of geology and geological engineering at the Colorado School of Mines and director of the Potential Gas Agency, which provides technical assistance to the PGC. Supplies in the Appalachian basin alone are calculated at 227 TCF, with the Marcellus accounting for the bulk of that. And Curtis says he expects that even more shale gas will "be in the mix" in the committee's next assessment.

Indeed, some geologists believe that gas supplies in the Marcellus and other shale deposits might be even more abundant than the PGC estimates. In January 2008, Lash and Terry Engelder, a colleague at Pennsylvania State University, calculated the amount of recoverable gas in the Marcellus deposit at 50 TCF. But initial drilling efforts in the region have gone so well that Engelder now puts the recoverable supply of gas at 489 TCF. If that's correct, it makes the Marcellus the second-largest natural-gas field in the world; only a massive offshore reserve shared by Iran and Qatar is larger.

Natural gas offers advantages over other fossil fuels. It burns cleaner than coal, producing much less carbon dioxide. Since coal-fired power generation is responsible for a third of U.S. carbon dioxide emissions, replacing at least some of that coal with gas could significantly reduce such pollution. And using natural gas to replace gasoline and diesel fuel in vehicles could reduce the country's reliance on foreign oil.

But it's still uncertain how the large supply of natural gas will actually change U.S. energy consumption. Coal is generally cheaper than natural gas, so it remains the fuel of choice for most power producers. Meanwhile, car and truck makers have no economic reason to start producing natural-gas-fueled vehicles, and there's no infrastructure in place to refuel them in any case. In the absence of federal policy changes, the EIA predicts, demand for natural gas will stay relatively flat for the next several decades.

Liberal Washington-based lobbying groups, gas-industry interests, and environmental groups are pushing for policies to favor natural gas in the country's energy mix, citing its environmental and national-security benefits. If those groups can persuade leg-

islators, incentives to increase use of the fuel could be a key part of the federal energy bill being debated in Congress this fall. Previously, policy makers presumed that natural gas was a "declining resource," says Reid Detchon, executive director of the Energy Future Coalition, a Washington-based advocacy organization. But now, he says, it's possible to develop an energy policy based on "as much gas as you need."

"It doesn't matter what the exact number is," says Mark Zoback, a professor of geophysics at Stanford University. "The numbers are all so big it means we have an extremely large domestic resource that is going to play a significant role in the country's energy future." Natural gas is not a complete solution, he cautions. Still, he says, "it's not unreasonable that over the next decade or two we could completely get off coal, using gas as the principal fuel for electricity generation. I don't think natural gas is an alternative to renewables, but I do think it is by far the best fuel to use as we transition away from fossil fuels."

### GAS COUNTRY

The rush to drill the Marcellus shale for gas is already under way in Pennsylvania. According to a report released this summer by Penn State, drilling in the Marcellus will generate $3.8 billion and create more than 48,000 jobs in 2009. And the business of extracting natural gas from the deposit "is still in its infancy," says Robert Watson, an associate professor emeritus of petroleum and natural-gas engineering and coauthor of the report. "It's a brand-new industry."

Not only does natural gas lie under 60 to 65 percent of the state, Watson says, but many of the most promising drilling areas are adjacent to existing pipelines that can cheaply transport it throughout the Northeast, the world's largest market for the fuel. "Some of the pipelines go right over the heart of the Marcellus shale," he says. "You have a well, and next to it you have a [pipeline] that goes right into New York City." Watson predicts that gas drilling will generate $1 trillion over the hundred-year life of the shale development and create some 120,000 jobs for the state by 2020. "Pennsylvania has the potential to become an OPEC of natural gas," he says. "It's mind-boggling. It will have an impact on Pennsylvania's economy not seen since the collapse of the steel industry."

His seemingly hyperbolic assertion becomes more plausible when you visit southwestern Pennsylvania, an area known for steel production and coal mining. Tough times for steel have left behind abandoned, rusting factories and, until recently, economic hardship. These days, brand-new four-wheel-drive pickups and heavy industrial drilling equipment fill the rural

roads. Tucked away among the rolling hills and small farms are dozens of new gas wells. Occasionally, a tall drilling rig peeps over a ridgeline.

One of the companies leading the Pennsylvania gas rush is Range Resources, a Fort Worth–based firm that drilled the first commercial wells in the Marcellus shale in 2004. At one of Range's drilling sites, about 45 minutes south of Pittsburgh, a massive, multimillion-dollar rig rises high above the quiet farmland. The rig will drill half a dozen wells spaced just a few feet apart; once it has finished drilling a well, hydraulic jacks will lift the tons of equipment and "walk" it into position for the next one. Beside the drilling site is a small pond lined with plastic, filling up with the mud and debris that spurt from the well.

Range and other gas producers rely on drilling techniques that have been used for the past decade in the shale-gas fields of northeast Texas. Inside the trailer that serves as a field office, the complexity of the task is evident. On a wall is a chart mapping the drilling plans. The drill bit will head down more than a thousand meters through various types of sediments. Then, over the course of roughly 275 meters, it will gradually turn 90°, so that when it enters the layer of Marcellus shale at around 2,000 meters, it will be traveling horizontally through the gas-rich rock. Drillers can control the location of the bit to within several centimeters. Staying within a six-meter window, the bit will follow the Marcellus layer for up to 1,600 meters. The horizontal approach is crucial, allowing the well to tap into a large area of the shale layer. Eventually, the several wells at the site will spread out underneath the countryside, draining gas from hundreds of acres of shale.

The trickiest part of the operation comes after the drilling is done and the large rig is removed. A small armada of specialized equipment, including dozens of tanker trucks filled with water, will move in to perform a procedure called hydraulic fracture stimulation, or hydrofracturing, which is designed to get the gas flowing efficiently into the well. Although the Marcellus shale is soaked with gas, the rock holds the hydrocarbon tightly trapped. To allow it to escape, engineers will force millions of gallons of water down the well and into the shale formation at high pressure. If all goes well, the natural gas will rush out of the shale and into the pipe after the water is pumped back out.

That the process works is a tribute to the wonders of geology and the ingenuity of the drilling engineers. Like the black shale on the shores of Lake Erie, the Marcellus shale is riddled with tiny natural fractures created million of years ago as the newly formed hydrocarbon gases expanded. The high-pressure water, which is mixed with fine sand and chemical additives, works to enlarge those cracks. The results: gas-permeable zones of damaged rock a hundred or more meters across, radiating out from the well pipe.

Geologists like Gary Lash and Terry Engelder have long known that the black shale in the Appalachian basin contains large amounts of natural gas. In fact, the nation's first natural-gas well was drilled in Fredonia, NY, in 1825, a few miles from Lake Erie; wooden pipes were built to transport the fuel so that it could light houses in the town. But the geologists have been surprised to discover that so much gas can be recovered economically. After Range released its initial drilling results in 2007, Engelder recalls, he was asked during a conference call with investors in New York just how much natural gas the Marcellus shale contained. It wasn't a calculation he had ever bothered to do. Engelder remembers pausing and then answering, "I'm not sure, but by the end of the day I will be dead certain." He did some calculations based on the size of the formation and the likely gas content of the rock; then he called Lash and asked him to do his own. The next day, Lash called back with his numbers. They had come to the same conclusion, says Engelder: "Holy cow, there's a lot of gas."

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### BUILDING BRIDGES

The arguments in favor of using more natural gas and less coal and petroleum are, at least at first glance, straightforward. Coal-fired plants generate about 50 percent of the electricity used in the United States, but they produce 82 percent of the power industry's carbon dioxide emissions. Burning natural gas produces roughly half as much carbon dioxide as coal. What's more, plenty of existing gas-fired power plants already have excess capacity, since they are generally used as backup to coal plants at times of peak electricity demand.

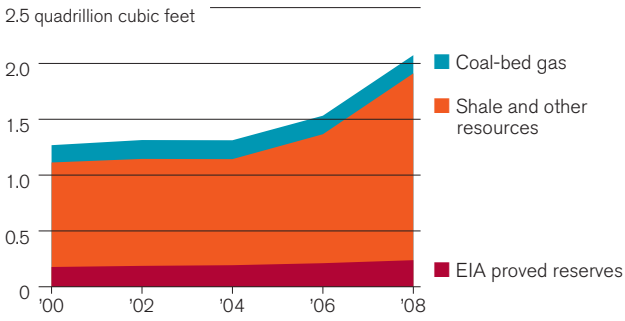
It's also easy, from a technological perspective, to substitute natural gas for gasoline or diesel fuel in cars and trucks. Unfortunately, this wouldn't reduce greenhouse-gas emissions nearly as much as replacing coal in power production. A natural-gas car emits about 25 percent less carbon dioxide than a gasoline-powered vehicle, but since transportation accounts for only about a third of U.S. greenhouse-gas emissions, even switching over all the country's vehicles to natural gas would reduce overall emissions by just 8 percent. Still, using natural gas in a portion of the nation's fleet vehicles, such as buses and taxis, would

## GAS GLUT

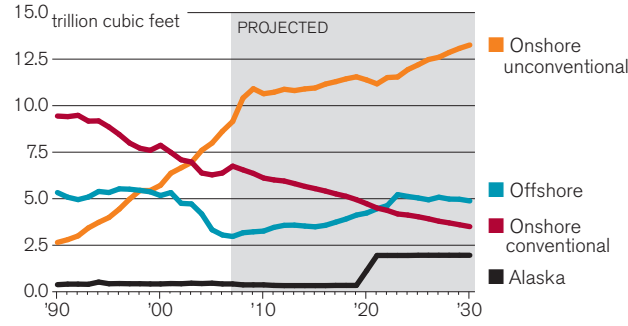
Estimates of recoverable natural-gas resources in the United States have risen dramatically in the last several years.

Most of the increase will come from shale gas and other unconventional resources, where production is expected to grow sharply while other production flattens or declines.

NATURAL-GAS RESOURCES

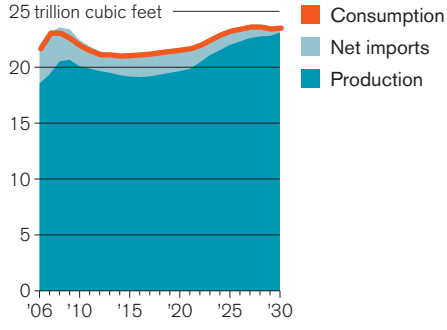



SOURCES OF GAS (TCF/YEAR)

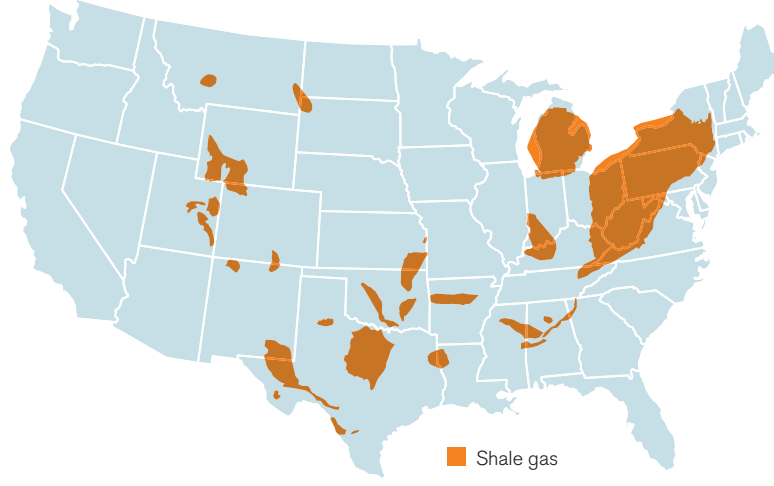



However, despite the ample supplies, natural-gas consumption is not likely to increase significantly without changes in energy policy.

NATURAL-GAS PRODUCTION AND CONSUMPTION




WHERE THE SHALE GAS IS

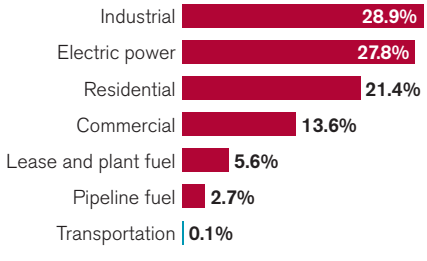



## POWERING UP

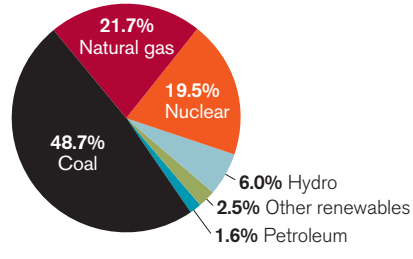
Natural gas finds a range of uses in the United States, including home heating. Advocates hope that more can be used in electricity production and in transportation.

Using natural gas to displace coal in electricity production could significantly reduce carbon dioxide emissions. Natural gas produces about a half the carbon dioxide emissions of coal, which accounts for a disproportionately large percentage of the power industry's carbon dioxide pollution.

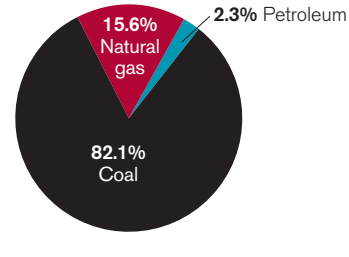
U.S. USE OF GAS (2008)




ELECTRICITY GENERATION (2007)




CARBON DIOXIDE EMISSIONS FROM ELECTRICITY GENERATION (2007)




*Sources: Potential Gas Committee (Natural Gas Resources); EIA*

TOMMY McCALL

be relatively simple and could help reduce dependence on imported petroleum.

In mid-August, the Energy Future Coalition and the Center for American Progress, an influential Washington group with close ties to the Obama administration, released a paper called "Natural Gas: A Bridge Fuel for the 21st Century." The timing of the report was triggered by the recent shale-gas findings and the desire to make natural gas a part of the discussion as Congress debates an energy bill. Proposed provisions in that bill, such as a cap-and-trade program that would effectively put a price on carbon dioxide emissions, could create a strong and growing market for this fuel. Once the carbon price reaches $20 to $30 a ton, says the Energy Future Coalition's Detchon, "it would be economically advantageous for utilities to switch to gas from coal." Detchon also favors a "low-carbon" mandate, which would require utilities to use natural gas for a certain percentage of their electricity production, and incentives for power producers to close down their oldest and dirtiest coal-fired plants.

Such policy changes are critical to encouraging further drilling in shale-gas deposits, says Jeff Ventura, the COO of Range. Prices for natural gas peaked at $13 per thousand cubic feet (MCF) last year, but oversupply and lackluster demand depressed them to around $3 per MCF this summer, the lowest level since December 2001. As a result, drilling slowed down, almost reaching a standstill in many regions of the country (though drilling in the Marcellus has actually increased). A "reasonable price" of around $6 to $8 per MCF, Ventura says, would enable drilling companies to more fully exploit shale gas. Getting back to that price will require not only an economic recovery but also policies that increase demand by influencing power generators to shift to natural gas. "That is something that could happen immediately," he says. "More power generation from natural gas would have an immediate impact."

Drilling for shale gas could also provide a less obvious environmental benefit, if research begun by the Stanford geophysicist Zoback is successful. Fossil-fuel power plants, whether they use coal or natural gas, will eventually need to capture and sequester their carbon dioxide emissions. That means finding a safe, economical way to store carbon dioxide so that it cannot leak out. Zoback believes that shale deposits might provide one solution.

Zoback is testing the feasibility of a process that could trap carbon dioxide in depleted natural-gas wells—and wring additional productivity from them at the same time. It is thought that at least some of the methane in the shale is adsorbed to the sediments: the gas molecules form a thin film that adheres to the surface of the organic material and clay in the deposits. Preliminary tests have shown, however, that carbon dioxide binds to these materials more strongly than methane does. Carbon dioxide pumped into wells that have grown less productive, Zoback believes, could displace the adsorbed methane, which would then flow out of the shale and into the well. If it works, the process would free extra natural gas in these wells while confining the carbon dioxide securely underground.

Zoback says it will be years before he knows whether the process works. "Of course, there is a long way from concept to implementation. And there are a hundred and one questions that need to be answered," he says. But, he suggests, the recent slowdown in gas drilling provides an opportunity to test the idea before the pace of drilling picks up again, as he expects it to in 2011 or 2012. Zoback notes that pipelines are now used to deliver carbon dioxide to oil-drilling sites to enhance production; a similar infrastructure, he says, could be built around shale-gas wells. And, he says, building some of that infrastructure while developing shale-gas drilling will make carbon storage much more practical.

### DREAM WORLD

Still, not all experts think it's wise to rapidly expand the market for natural gas. Simply put, they worry that the country could become addicted to yet another fossil fuel—one that could turn out, over the long term, to be far less abundant and more expensive than many now predict.

The experience of Great Britain in the late 1980s provides a sobering example. The country was adjacent to an enormous, underdeveloped resource of natural gas in the North Sea. At the time, the Conservative government headed by Prime Minister Margaret Thatcher was fighting with the coal miners, and natural gas looked like an economically and politically attractive fuel. So government and industry pushed forward with what became known as the "dash for gas," allowing the use of that fuel in power plants for the first time. The country's coal industry all but disappeared, and nuclear power was largely neglected. "The whole country moved very rapidly toward building new gas-fired power stations," recalls Tony Meggs, who was then an executive at BP responsible for a building an export pipeline for the fuel. "We started exploiting the underdeveloped gas fields, and it was great. We were very happy."

But in retrospect, says Meggs, now a visiting engineer at MIT and codirector of the school's forthcoming report on natural gas, the rapid expansion of the market in Great Britain turned out to be "bad policy." These days, he says, the U.K. imports substantial amounts of the natural gas it depends on for much of its electricity generation; by 2020 it will be forced to import 70 percent, most of it from continental Europe. "So we went from a position of great supplies and security, with everyone saying there's a lot a gas, to a position that from an energy-security perspective is very unat-

WWW Learn about the geology of the Marcellus shale and see how Range Resources and others drill for natural gas: **technologyreview.com/naturalgas**

"I am a big fan of clean natural gas, but there is a very big danger of getting everybody revved up about gas and losing sight of the fundamental technological transformation that is needed," says energy-policy expert David Victor.

tractive," Meggs says. "It is very important that the U.S. doesn't go the same route, expanding markets and using resources inappropriately and then ultimately becoming import-dependent."

While Meggs calls the shale-gas supply in the United States a "great blessing," he cautions that it is still unclear how large a resource it will be, because drilling for it "is a relatively young phenomenon." Any energy policy must take those uncertainties into account, he says. MIT's natural-gas study, for example, will focus on "not just how much is there but how much it costs to get it out of the ground, how long it will last, and what is the range [of uncertainties], both in terms of cost and in terms of ultimate recoverability."

The worry, of course, is that much less gas than experts have estimated will turn out to be recoverable from shale at an acceptable environmental and economic cost. Jay Apt, executive director of the Carnegie Mellon Electricity Industry Center in Pittsburgh, is blunt: "We're in an early stage of a shale boom. Every practitioner in a boom thinks it will last forever and is surprised, in five or seven years, that it isn't going to last forever." Apt predicts "an inevitable downgrading of the number of cubic feet that these deposits can supply." After all, he says, "there is a difference between what Mother Nature gave you and what the town will allow you to extract." The gas producers' extensive land and water use is already creating a backlash in Pennsylvania, he says. And the danger of rapidly converting more electricity plants to natural gas is that once shale-gas supplies "top off," power producers will be reliant on imports and vulnerable to volatility in their prices.

Some energy experts say that even if supplies of natural gas remain abundant, it's unclear to what extent power producers will switch to the fuel, and how long it will take if they do. Many gas advocates display a "practical naïveté" about the conversion of coal-fired power production, says David Victor, director of the International Law and Regulation Laboratory at the University of California, San Diego. "If you look at the quantity of gas needed to replace all the coal plants in the United States, you're talking about increasing gas consumption by something like 50 percent," he says. "It's a huge number." Such a large increase in production will require extensive shale drilling, some of it in heavily populated locations. And, he says, "we don't know what [the shale-gas drilling] looks like on a truly massive scale." Many of those advocating a large-scale shift to natural gas are "living in a dream world," Victor says. "They haven't worked out the practical details."

Generating electricity with more natural gas and less coal could clearly decrease carbon dioxide pollution. Says Victor, "If shale gas plays out at very large volumes and at low cost, then it will be a cost-effective way of making substantial reductions in emissions." But, he says, those reductions won't be enough to meet the long-term goal of cutting the nation's overall carbon dioxide emissions 80 percent by 2050, as President Obama and a number of other political leaders have advocated. The switch to natural gas, he says, "buys you a little time" before other changes can be made, such as introducing more wind, nuclear, hydroelectric, solar, and other zero-carbon power sources. "The concern is that natural gas is a bridge to nowhere," Victor says. "And it could be a very costly bridge to an outcome that doesn't readily get you to the 80 percent reductions."

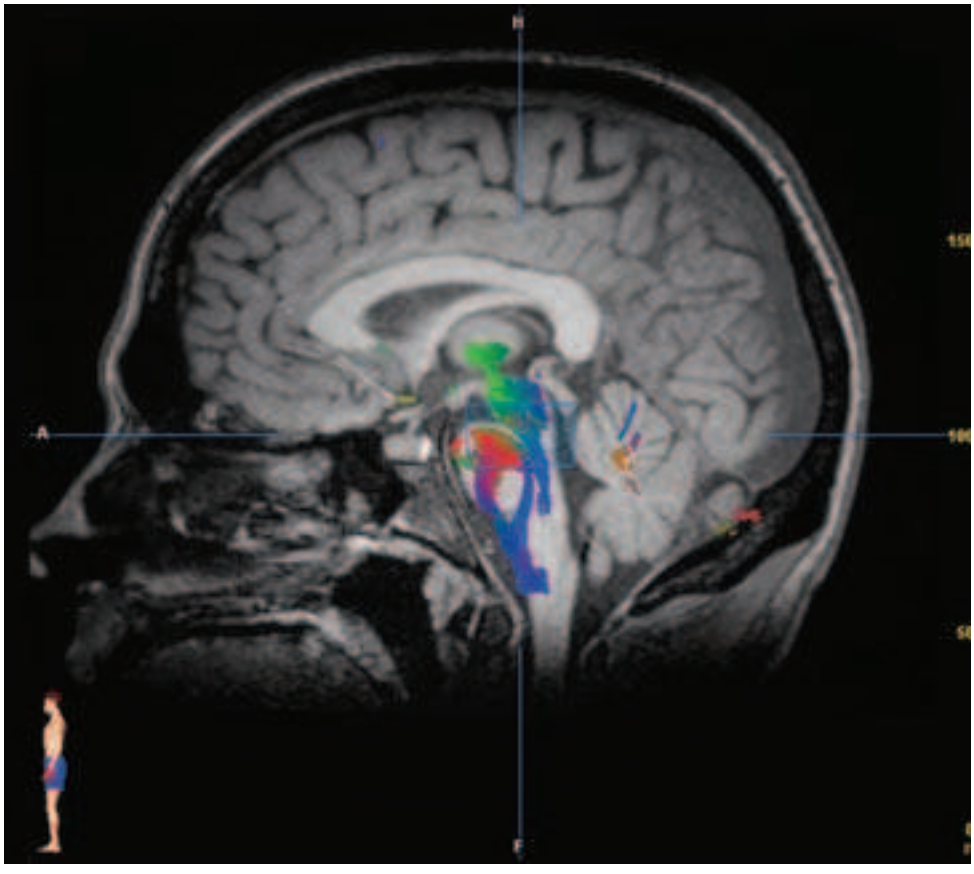
From a technology perspective, natural gas and renewable sources, such as wind and solar, could complement each other. Natural-gas-fired turbines could be used to generate electricity when the wind isn't blowing or the sun isn't shining. But the economic and political relationship between natural gas and renewables is more complicated. If federal and state policies continue to mandate that power producers use more renewables, the electricity industry is likely to concentrate its new capacity on those technologies while keeping its low-cost coal-fired power plants. Policy will drive the use of renewables, and economics will drive the use of coal. Natural-gas plants will be squeezed out.

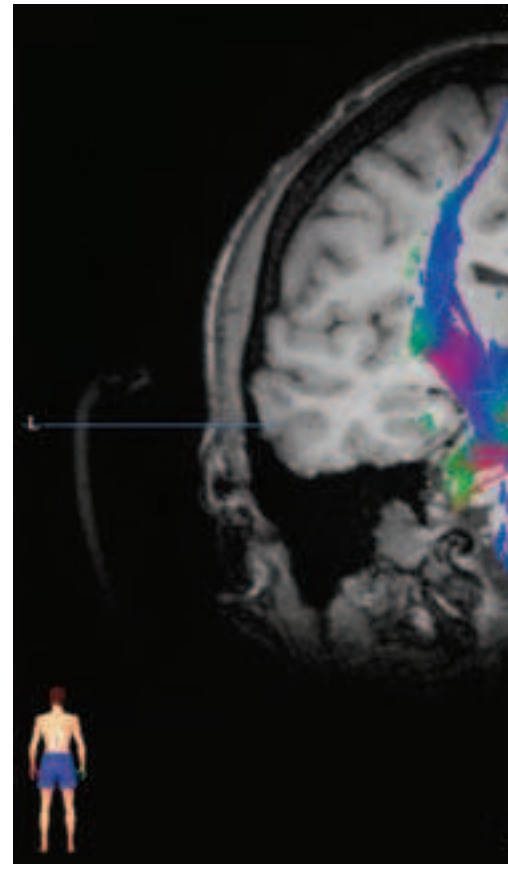
Then again, a focus on natural gas as a way to trim carbon dioxide emissions could divert attention—and money—from the need for zero-carbon technologies. "I am a big fan of clean natural gas, but there is a very big danger of getting everybody revved up about gas and losing sight of the fundamental technological transformation that is needed," says Victor.

The availability of vast natural-gas resources in the Marcellus shale and similar sediments around the United States has changed energy calculations in a fundamental way. The discovery of this large and seemingly economical new source of fossil fuel has surprised even geologists who have spent their careers studying the shale. Little wonder, then, that policy makers and politicians are just beginning to try to figure out what the discoveries mean.

It's not clear how—or even whether—those responsible for energy policy will take advantage of the opportunity. At best, the newly identified supplies of gas will buy time, providing a chance to reduce greenhouse gases while more innovative technologies are developed and deployed. At worst, the country will burn through large volumes of this fuel only to find that we haven't reduced carbon dioxide emissions very much—and that we've put off investing in research to create cleaner technologies. TR

DAVID ROTMAN IS THE EDITOR OF *TECHNOLOGY REVIEW*.





# Intelligence Explained

## Tracking and understanding the complex connections within the brain may finally reveal the neural secret of cognitive ability.

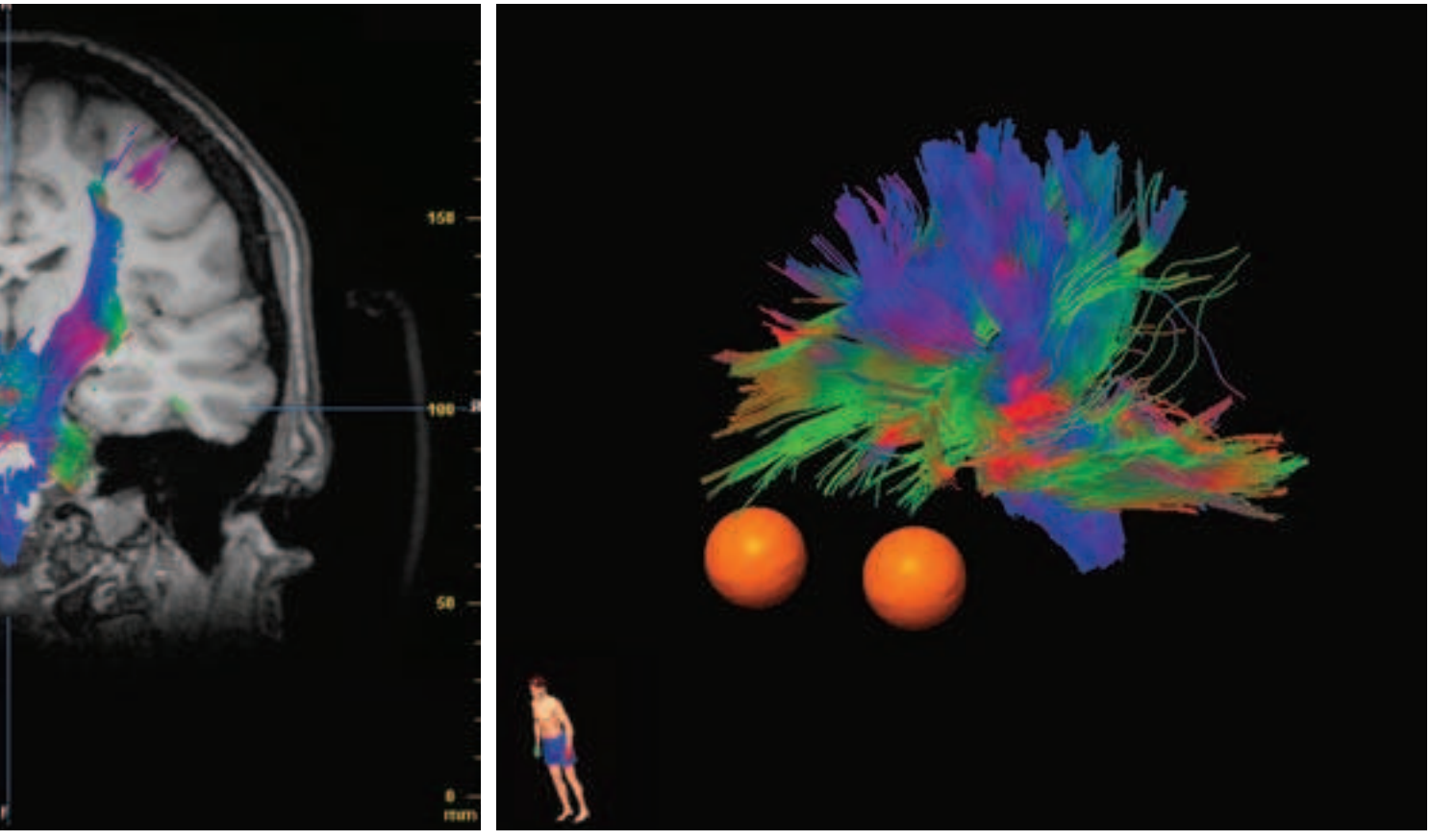
*By* EMILY SINGER

A series of black-and-white snapshots is splayed across the screen, each capturing a thin slice of my brain. The gray-scale pictures would look familiar to anyone who has seen a brain scan, but these images are different. Andrew Frew, a neuroscientist at the University of California, Los Angeles, uses a cursor to select a small square. Thin strands like spaghetti appear, representing the thousands of neural fibers passing through it. A few clicks of the cursor and Frew refines the tract of fibers pictured on the screen, highlighting first my optic nerve, then the fibers passing through a part of the brain that's crucial for language, then the bundles of motor and sensory nerves that head down to the brain stem.

Frew is giving me a tour of my white matter—the tissue connecting the neurons, or nerve cells, that make up gray matter. Something about the twisting, turning neural wires that ferry information between the neurons—their individual thickness, perhaps, or their abundance, or the specific paths they take from one part of the brain to another—may explain, at least in part, the variations in human intelligence.

Scientists have been searching more than two centuries for the source of intelligence—the general cognitive ability often quantified in the form of IQ. With the advent of technologies such as magnetic resonance imaging (MRI), researchers concentrating mainly on gray matter have been able to map the parts of the brain that

ANDREW FREW/BRAINLAB



BRAIN MAP Software called BrainLab analyzes data collected during a specialized MRI scan of the author's brain in order to create a neural wiring map. The first two images show cross-sections. Specific subsets of wires are highlighted (the color indicates the direction of the wiring going through that slice). The cross-sections are computationally stitched together to create a three-dimensional image (far right).

appear to play a role. But this has taken them only so far, and the focus on gray matter has not told the whole story. Not until the last few years, as new variations of MRI home in on the brain's white matter, has a deeper understanding begun to emerge. "Scientists are now able to switch the focus from particular regions of the brain to the connections between those regions," says Sherif Karama, a psychiatrist and a neuroscientist at McGill University's Montreal Neurological Institute. Their initial findings have led Karama and others to believe that neural wiring and the way it carries information around the brain may be crucially important to IQ.

Until fairly recently, only a few scientists were studying how brain structure might be related to IQ, in part because the idea of a biological and genetic basis for intelligence has long been controversial. Since people from different ethnic groups often score differently on intelligence tests, such studies may raise contentions of racism, and critics fear potential abuses such as discrimination in education or employment. Nonetheless, new imaging techniques have allowed types of studies never before possible, and the number of research groups focusing on this question is growing quickly. Many of these groups are setting their sights on white matter.

The hope is that finding the brain areas and circuits involved in intelligence will provide new insight into neurological and psychiatric diseases that impair cognition, such as Alzheimer's and schizophrenia. "If you want to understand cognitive decline, you need to understand how cognition is manifested and put together in the brain," says Rex Jung, a neuroscientist at the Mind Research Network in Albuquerque, NM. The research may also improve understanding of learning disabilities such as dyslexia and ADHD, perhaps leading to better treatments. But other potential applications could be more controversial. Some scientists envision a day when brain scans are used to estimate IQ. Sandra F. Witelson, a neuroscientist at the Michael G. DeGroote School of Medicine at McMaster University in Ontario, says, "It's not a wild guess to say that sometime in the future, brain scans will be part of a group of tools that try to indicate what level someone's ability is going to be."

### BIG BRAINS

Neuroscientist Paul Thompson is one of those researchers studying brain structure and IQ, but that wasn't what he planned on when he started his lab at UCLA: he focused on the wave of changes in the brain that characterize Alzheimer's and schizophrenia. Because serious cognitive deficits accompany both of

those diseases, however, Thompson and his collaborators tested cognitive function in their subjects. When they began to look more closely for variables that correlated with brain structure, they found that intelligence seemed to be among the most significant. "IQ came in as a key factor that determines how the brain looks," Thompson says.

Scientists who study intelligence typically define it in comparative terms, as a general cognitive ability measured against a mean. A quantifiable "general intelligence factor," known as *g*, can be statistically extracted from scores on a battery of intelligence tests. While some people clearly have particular areas of talent, those who score well on one test are likely to score well on others as well, reflecting a higher *g*.

Researchers have yet to find a simple neural explanation for *g*. In 2001, Thompson showed that it is correlated with volume in the frontal cortex, a result consistent with a number of studies that have linked intelligence to overall brain size. But size is a crude measure: while larger brains may be smarter on average, it's not clear if that's because they have more nerve cells, more connections between cells, or more of the fibers that carry neural signals. Any of these factors can result in a larger brain or thicker cortex, but neither of these things is necessary for great intelligence. Studies of Albert Einstein's brain, for example, have found that it was typical in size, or even a bit on the small side. (It was missing a wrinkle in the inferior parietal lobe, which is behind the frontal cortex; some have speculated that this quirk allowed the neurons in that region to communicate more effectively.)

As structural brain imaging has become more sophisticated, scientists have focused on sections of the brain involved in specific tasks, including sensory processing, memory, attention, and decision making. Different studies have connected different areas with intelligence, however, making it difficult to come to an overarching conclusion about its anatomical basis.

But what if the key to intelligence is neither an individual area of the brain nor its total volume but the network over which information is transmitted and integrated? In 2007, Jung and Richard Haier, now professor emeritus of psychology at the University of California, Irvine, developed the first comprehensive theory drawn from neuroimaging of how the brain gives rise to intelligence. Gathering information from 37 published papers that had used imaging to study intelligence, they mapped out the brain areas that had been pinpointed in at least a third of the studies to sketch a network of regions spanning the frontal and parietal lobes.

The network consists of about 10 nodes, or clusters of cells, that had been linked to attention, working memory, and facial recognition, among other cognitive functions. Applying existing theories of how information flows in the brain, Jung and Haier hypothesized that neural signals travel from nodes near the back of the brain, where sensory data is collected and synthesized, to those in the frontal lobes, which are responsible for decision making and planning. The connections between these nodes, they argued, are just as critical as the nodes themselves. "If the nodes of a network aren't communicating effectively and efficiently, then the network won't function efficiently," says Jung.

The theory was provocative, but the data used to develop it had a major limitation: the published studies had focused primarily on gray matter. As for the connecting white matter, Jung and Haier inferred its paths from the locations of the key nodes and existing maps of neural anatomy. They didn't look directly at the white matter itself, largely because they lacked the technology to do so.

### CONNECTIONS

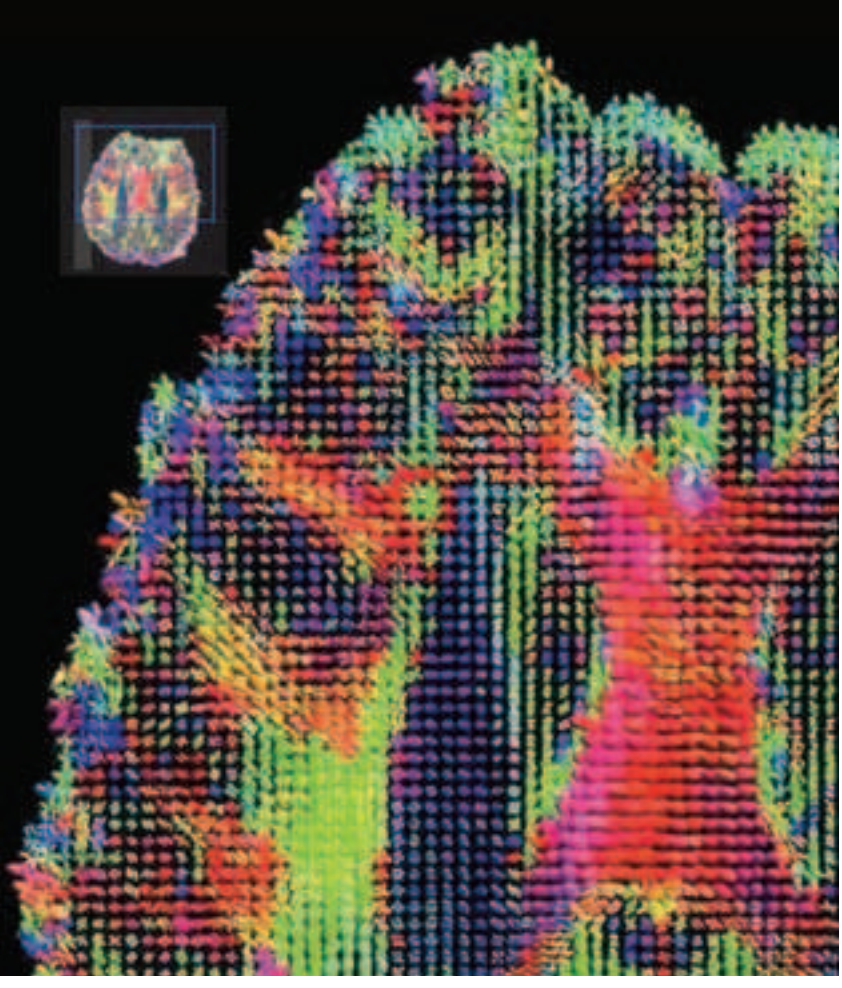
By volume, gray matter makes up roughly half the human brain. The other half is white matter, consisting of filament-like neural projections wrapped in a fatty material called myelin; such a high proportion of white matter appears to be unique to humans. As we "evolved from worms to humans," says George Bartzokis, a professor of psychiatry at UCLA, the number of non-neural cells in the brain increased 50 times more than the number of neurons. He adds, "My hypothesis has always been that what gives us our cognitive capacity is not actually the number of neurons, which can vary tremendously between human individuals, but rather the quality of our connections."

Thanks to their layer of insulation, which prevents leakage of electrical impulses, myelinated nerve fibers can send signals about 100 times as fast as unmyelinated ones. The myelin also allows more information to be sent per second by reducing the waiting time between signals. The result is that neurons can process 3,000 times as much information as would otherwise be possible. That capacity, Bartzokis believes, is crucial for speaking and processing language.

The type of MRI typically used for medical scans does not show the finer details of the brain's white matter. But with a technique called diffusion tensor imaging (DTI), which uses the scanner's magnet to track the movement of water molecules in the brain, scientists have developed ways to map out neural wiring in detail. While water moves randomly within most brain tissue, it flows along the insulated neural fibers like current through a wire.

Most DTI scans break the MRI image into tiny areas and measure the diffusion of water molecules through each one in six to 12 directions, which is sufficient for detecting thick bundles of neural fibers. But places where wiring overlaps appear as a blur. Newer variations of diffusion imaging measure diffusion in 50 to 500 directions. Computer algorithms synthesize this data into a

WWW To see 3-D video of Emily Singer's brain scan and an interview with neuroscientist Richard Haier, visit **www.technologyreview.com/intelligence**



PAUL THOMPSON

PLOTTING DIFFUSION Water molecules in the brain diffuse along neural wires, allowing scientists to create, essentially, circuit diagrams. First, the most likely directions of diffusion are calculated for each two-cubic-millimeter patch of the brain, generating 3-D shapes for each point, as shown above. Specialized software calculates the path of neural wires on the basis of these shapes. This method can distinguish overlapping wires, while more conventional imaging cannot.

three-dimensional picture showing the most likely paths of nerve fibers through each area, and then stitch together the information from multiple points to create a wiring map.

The strength of the diffusion signal—the extent to which it reveals a clear direction—is used to gauge how organized the fibers of the white matter are. A stronger diffusion signal may indicate more fibers or thicker myelin; scientists don't yet know. But the newer diffusion imaging methods have revealed a strong correlation between the strength of this signal—what researchers refer to as the "integrity" of the white matter—and performance on a standard IQ test. "DTI turns out to be one of the most sensitive MRI measures we have for cognitive function," says Vincent Schmithorst, a neuroscientist at Cincinnati Children's Hospital.

Thompson refers to his diffusion maps as "pictures of mental speed." Previous research has repeatedly linked IQ to processing speed, and other studies show that processing speed in turn is tightly linked to the quality of one's white matter. Does that mean intelligence is determined by how fast the brain works? If so, does finding the key to processing speed in the brain mean researchers have finally found the secret to intelligence?

In reality, speed is probably not the only determinant of IQ. "One of the things that is important for IQ is frontal-lobe function, which is involved in planning, decision making, and weighing evidence," Thompson says. "I wouldn't think of those skills as being entirely reliant on mental speed."

Some of the newest theories of intelligence suggest that the crucial factor may be how efficiently information moves around the brain, rather than just how quickly. In a recent study led by Martijn P. van den Heuvel, a neuroscientist at University Medical Center Utrecht, in the Netherlands, researchers defined efficiency as the number of links it takes to get from one node to another—both in specific brain areas and all over the brain. Just as a direct flight from Paris to Chicago would be considered more efficient than one with a layover in London, a direct link between two parts of the brain would be more efficient than an indirect route.

Van den Heuvel and colleagues found that people with above-normal IQs of 120 and up had the most efficient brain networks. "Our hypothesis is that IQ is about how the human brain can integrate different types of information, how easily it can get information from one brain region to another," van den Heuvel says. "These activity patterns are highly influenced by white-matter structures in the brain, how the brain is connected."

Richard Haier and his collaborators are now working on a new method of measuring information flow around the brain using magnetoencephalography, or MEG. MEG measures the magnetic fluctuations around neurons as they fire, allowing scientists to track the millisecond-scale sequence of neural signaling in the brain as people perform different tasks, such as pressing a button in response to a light. Researchers hope to figure out how the flow of these signals differs with intelligence—whether smarter people follow the same sequence but faster, for example, or whether their brains skip a few steps in a circuit. "When you add the timing of the nodes and networks," says Jung, "then we're really talking about how the brain works in real time."

### IMPROVING IQ

If white matter plays a key role in intelligence, is there a way to enhance it? Does it give us ways to make ourselves smarter, or to help people with neurological and psychiatric disorders that affect cognitive skills?

It's likely that the quality of white matter is at least partly genetically determined and, therefore, difficult to change. The size of the corpus callosum, the thick tracts of white matter connecting the two hemispheres of the brain, is about 95 percent genetic. And about 85 percent of the white-matter variation in the parietal lobes, which are involved in logic and visual-spatial skills, can be

attributed to genetics, according to Thompson. But only about 45 percent of the variation in the temporal lobes, which play a central role in learning and memory, appears to be inherited.

Thompson is now trying to identify specific genes that are linked to the quality of white matter. The top candidate so far is a gene for a protein called BDNF, which promotes cell growth. People with one variation have better-organized fibers, he says.

But environmental factors also play a role. Rodents raised in a stimulating environment have more white matter. And research suggests that the apparent IQ difference between people who were breast-fed and bottle-fed as babies may arise because breast milk contains omega-3s, fatty acids involved in the production of myelin; as a result, some baby formula now includes these compounds.

Hope remains for those who passed the baby-formula stage long ago. Although the adult brain isn't as malleable as a young brain, and is therefore less easily influenced by environmental factors, evidence is growing that the adult brain is still remarkably plastic. Scientists haven't yet studied white matter enough to know how to improve it directly, especially in healthy people. But exercise, diet, and mental activity have all been shown to boost brain health and decrease the risk of dementia, a disorder that has been linked to white-matter damage. And other studies have shown that just a few months of practicing a new skill can enlarge certain parts of the brain, including parts of the frontal cortex involved in motor planning and parts of the temporal lobes that integrate visual, auditory, tactile, and internal physiological information. Similar studies on ways to improve the quality of white matter are under way.

Although looking at images of my own white matter was fascinating, it was not deeply illuminating. The scan gave me no indication of how efficient or flexible my mental processes are. And, the researchers told me, not even the most astute neuroanatomist would be able to glean a general sense of my cognitive capabilities from my brain scan.

Learning more about the role of white matter in intelligence will give scientists a fuller picture of how brain anatomy influences cognition. It could help explain how differently structured brains might produce the same IQ, or whether particular patterns—thick white matter here, a large chunk of gray matter there—are linked to particular cognitive strengths and weaknesses. "One of the key findings that has come out of the last decade of studies of intelligence is the fact that the brain can generate the same IQ score a number of ways," says Haier. Intelligence is characterized by "individual differences in learning, memory, and attention and how they are integrated in any one individual." Haier envisions a day when brain scans could alert teachers to the cognitive strengths and weaknesses of each student, so that lessons could be individually tailored. It might be possible to derive much the same information from extensive cognitive testing, but such testing is rare because it's expensive and time consuming. A 15-minute brain scan, on the other hand, might be applied much more broadly.

Although it's not yet possible to estimate someone's IQ from a brain scan, some scientists say that day may not be far off. "For a very simple example," says Haier, "suppose the total amount of gray matter in several areas is a good correlate of IQ, and this correlation gets better if we add additional scan information—perhaps the amount of white matter in other areas or the amount of activation in certain areas while a problem is solved. We don't yet know which combination of brain parameters will be most predictive of psychometric IQ or other intelligence factors or mental abilities, but we know how to find out. Once funding is available to scan very large samples with multiple techniques and test everyone with a battery of psychometric measures, it's just a matter of time."

A neuroscientist envisions a day when brain scans could alert teachers to the cognitive strengths and weaknesses of each student, so that lessons could be individually tailored.

That could be a boon for physicians working with Alzheimer's patients or others suffering from diseases that cause cognitive damage. Some experts, however, fear it will create the sense that people's abilities are completely predetermined. Scientists working in the field argue that using a brain scan to quantify intelligence is really no different from using a standardized test like the SAT. But because a brain scan measures a physical property, it's likely to arouse even more concern than today's testing methods. "If you can estimate someone's IQ from a brain scan, even if it isn't any more predictive than an SAT [score], it gives the illusion that his or her future is fixed," says Karama.

In truth, it's not yet clear that brain scans would be any better than SAT scores at predicting an individual's cognitive function—or success in school, career, or life. Their value will depend on what we do with them. Perhaps, as with the SAT, training courses will be developed to help people improve their scores—to make better use of the network of connections in their brains. Says UCLA's Frew, "It's not just the tool. It's how well we are using it." TR

EMILY SINGER IS *TECHNOLOGY REVIEW*'S SENIOR EDITOR FOR BIOMEDICINE.

# Technology Review's Career Resources

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## Career Growth Profile

### Humayun Arif

**Age:** 55

**Job Title:** Space Initiatives Manager, Global Government Solutions Group

**Employer:** Cisco Systems, Inc.

**Graduate Programs:** MBA, Executive Program, Kellogg School of Management, Northwestern University

Humayun Arif has been instrumental in reshaping NASA's architecture for the next 30 years of space communication. He has played a key role in positioning Cisco Systems in NASA's $104 billion Constellation Program to return humans to the moon and go to Mars.

Last January, Arif embarked on yet another challenging mission: an executive MBA degree from Northwestern University's Kellogg School of Management. Never mind that he's a recognized expert in his field. Never mind that he's 55 years old and has more than 20 years' experience. Arif says he's in need of some education.

"Over the last few years, it has been readily obvious to me while interacting with Cisco's business units that there is strong interdependence of technical decision-making with business economics. One cannot be performed without the other," says Arif, who is a space initiatives manager for U.S. civil programs with Cisco Systems' Global Government Solutions Group. "The value of an MBA, has...clearly become evident."

Arif also admits that he is pursuing an executive MBA degree because his leadership skills could use some reinforcement – particularly in formulating strategies, solving problems and making decisions in a team environment.

"And finally, there is the age-related factor of keeping the brain engaged, given the current work scenario of never retiring," he says.

With increasing numbers of working professionals going back to school, universities are responding with flexible MBA programs, such as online and evening formats. An executive MBA program typically holds class every other weekend for two years, plus some weekday getaways for immersion workshops or a business consulting practicum. Arif says he opted for the executive program because it's geared toward professionals who have a minimum of 10 years' experience in their respective industries.

To read more about how Humayun plans to put his MBA to use, visit
**www.technologyreview.com/careerresources/.**

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# BRIEFING TRANSPORTATION

Nearly 1,500 cars are added to Beijing's roads daily.

XIAOYANG LIU/CORBIS

## Getting Beyond Petroleum Won't Be Easy

Transportation defines our civilization. Where we live and work, the structure of our cities, the flow of global commerce—all have been shaped by transportation technologies. But modern transportation's reliance on fossil fuels cannot be sustained. Passenger planes, trains, and automobiles were responsible for nearly four billion tons of carbon dioxide emissions in 2005—about 14 percent of the carbon dioxide emitted globally that year. If we continue to rely almost exclusively on petroleum to power these vehicles, they will be responsible for 11 billion to 18 billion tons of carbon dioxide emissions in 2050. That's because developing nations—which are home to 82 percent of the world's population and will be responsible for 98 percent of population growth in coming years—are on the verge of mass motorization. Auto ownership in the developing world is growing at a rate of 30 percent per year *(see "Cleaner Vehicles by the Million," p. 65)*.

In the developed world, carbon emissions from transportation are also a steadily growing problem. U.S. passenger transportation is responsible for 18 percent of America's

greenhouse-gas emissions. Reducing these emissions by transforming the habits of consumers in America's deeply entrenched car culture won't be easy, but it would yield significant global benefits.

Relatively wealthy U.S. drivers can afford to adopt new alternative transportation technologies, and after a century's dominance by the internal-combustion engine and gasoline, these technologies, such as electric vehicles and biofuels, are finally becoming competitive *(see "Petroleum's Long Good-bye," this page)*. But they still have a long way to go, and they must be fostered with coherent government policy *(see "Washington Backs Plug-ins," p. 67)* if they are to displace fossil-fuel power.

As our world continues to globalize and urbanize, the issue of congestion, on the streets and in the air, must also be addressed with the help of information technology that can allow cars and planes to organize themselves into efficient traffic patterns *(see "Urban Renewal" and "Satellites for Speedy Skies," pp. 67 and 64)*. Needed most of all is a coherent transportation policy that promotes alternatives to fossil fuels while mandating that gasoline- and diesel-powered cars continue to become more fuel-efficient. And as the world's population becomes increasingly urban, we need to modify the structure and operation of our cities so that someone who needs to buy groceries or get to work doesn't have to fire up an internal-combustion engine to do it.

*–Stephen Cass*

DATA SHOT

**2.3 kilograms**

The amount of carbon dioxide produced by burning a liter of gasoline in an engine. The emission ratio is 2.7 kg/l for diesel and 2.5 kg/l for jet fuel.


DAVID ROSENBERG/GETTY IMAGES

TECHNOLOGY OVERVIEW

# Petroleum's Long Good-bye

For the next few decades at least, liquid hydrocarbons—gasoline, diesel, and jet fuel—will continue to be the mainstays of transportation. They're cheap; refueling is fast; and their energy density, crucial to long-distance travel, is hard to beat.

"Advanced technology is going to happen slowly," says Daniel Sperling, the director of the Institute for Transportation Studies at the University of California at Davis and a member of the California Air Resources Board. "The focus needs to be on making conventional technology more efficient."

It should be possible to reduce the fuel consumption of a midsize sedan by up to 60 percent without sacrificing size or performance, using mostly existing technology. Lightweight materials will help. Advanced turbocharging and fuel-injection technology will extract more power from smaller engines that lose less energy to friction *(see "Research to Watch," p. 69)*. Similarly, making airplanes lighter and their engines more efficient could cut their fuel consumption 30 to 50 percent by 2020.

Biofuels should help curb petroleum consumption, although the contribution they make will depend on many factors, including the price of oil and the development of new technologies. The International Energy Agency has estimated that by 2050, ethanol and biodiesel could meet 13 percent of global demand for transport fuel. The U.S. Energy Information Administration estimates that biofuel consumption in the United States will increase from 7.7 billion gallons per year in 2007 to 35 billion gallons by 2030 while consumption of gasoline, diesel,

and jet fuel combined holds steady at about 220 billion gallons per year.

At first, most biofuels will be ethanol made from corn or sugarcane. The amount of ethanol that can be produced from these sources, particularly corn, is constrained by the need for farmland. What's more, the greenhouse-gas reductions achieved are minimal, because producing corn ethanol takes a lot of fossil fuel. But cellulosic sources of ethanol, such as switchgrass and wood, can be grown on marginal lands, greatly increasing potential fuel production. And the process of making ethanol from these materials consumes less fossil fuel. Corn ethanol contains roughly 1.3 to 1.7 times the energy of the fossil fuels used to make it; for cellulosic ethanol, it's about 4.4 to 6.1 times as much. By 2030, a significant portion of biofuels will be synthesized from biomass using biological and thermochemical techniques to create gasoline and diesel fuels. Such biofuels could even eclipse cellulosic ethanol.

It will take decades before anything other than liquid fuels powers a significant portion of the nearly one billion cars on the road. Still, cars will rely more and more on electricity. Hybrids, which accounted for only about 2 percent of U.S. sales of light-duty vehicles in 2007, could account for 40 percent by 2030. Then there are plug-in hybrids, which are just starting to be sold and which could account for 2 percent of sales by 2030. Unlike conventional hybrids, which derive all their power from gasoline-powered internal-combustion engines, plug-in hybrids have batteries that can be charged from the electrical grid, ideally using nighttime excess generating capacity. They can go the distance of an average commute on this energy alone, using an electric motor; an onboard gasoline engine kicks in for longer trips. Since some of the energy for propelling the car comes from power plants, overall greenhouse-gas emissions depend on the fuel those power plants use. Assuming typical driving patterns, a plug-in hybrid with a 20-mile electric range will generate about 325 grams of carbon dioxide emissions per mile if the electricity comes from a coal-powered plant (a conventional vehicle emits about 450 grams per mile). If the electricity comes from wind power, the hybrid will generate 150 grams per mile.

The high cost of batteries will initially slow the adoption of hybrids and all-electric vehicles *(see "Scaling Up Is Hard to Do," p. 64)*. Lithium-ion batteries that can provide a 40-mile range currently cost more than $16,000, according to an estimate by Carnegie Mellon University. But technological improvements and mass production could reduce this price by 75 percent or more. Meanwhile, researchers are exploring different chemistries, such as lithium-air batteries. These technologies could store 10 times as much energy as conventional lithium-ion batteries, extending range and potentially lowering costs. *—Kevin Bullis*

DATA SHOT

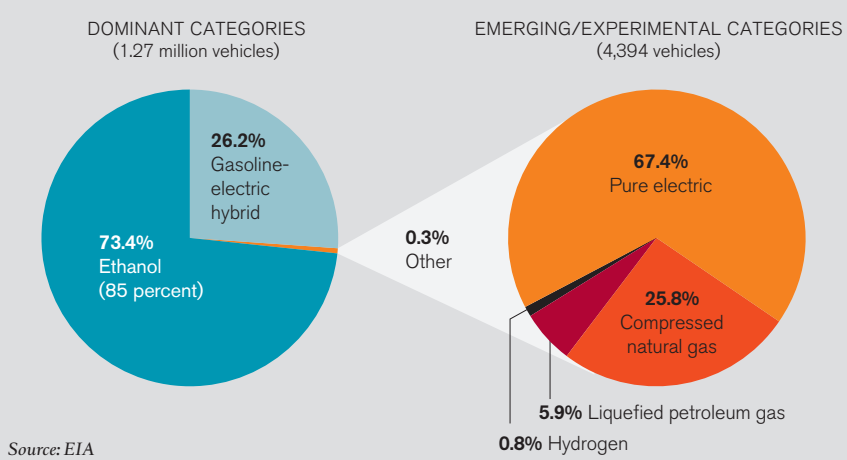
## 10.7 kilometers

The depth of the well drilled by BP to reach a giant oil field beneath the Gulf of Mexico. Advances in extraction technology have continually pushed back the date at which petroleum reserves are expected to be depleted.

## ETERNAL COMBUSTION?

Most of the popular alternatives to petroleum in vehicles continue to be liquid fuels

**Alternative-fuel vehicles in the U.S. by type**




*Source: EIA*

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LINCOLN
MERCURY
Powered by Microsoft
TURN-BY-TURN NAVIGATION
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THE VOICE-ACTIVATED IN-CAR TECHNOLOGY AVAILABLE
EXCLUSIVELY ON FORD, LINCOLN AND MERCURY VEHICLES.*
SYNC. Say the word.
hands-free calling • music search • vehicle health report • turn-by-turn navigation
business search • 911 Assist™ • real-time traffic • audible text • my favorites
Learn more about all SYNC features at syncmyride.com
*Driving while distracted can result in loss of vehicle control. Only use mobile phones and other devices, even with voice commands, when it is safe to do so.

INDUSTRY CHALLENGES

# Scaling Up Is Hard to Do

Transportation has a voracious appetite for energy. In 2008, the world consumed 1.3 trillion gallons of oil, most of it converted into gasoline and diesel and used to power vehicles. If biofuels or batteries are to satisfy a significant fraction of that appetite, production of these alternative power sources must be boosted significantly.

Cellulosic ethanol offers potential economic and environmental advantages over the corn- and sugar-derived ethanol that makes up the bulk of today's biofuel, and it should be a more scalable technology, because a wide variety of biomass can be used for feedstock *(see "Petroleum's Long Good-bye," p. 60)*. But to date, it remains expensive, in that huge capital investments are required. The largest project under way to produce advanced biofuels is Range Fuels' wood-to-ethanol plant in Soperton, GA, which is scheduled to begin operating early in 2010. The plant is being built with the assistance of $76 million in grants from the U.S. Department of Energy and an $80 million loan guarantee from the U.S. Department of Agriculture. It will initially produce just 10 million gallons of ethanol per year—a drop in the bucket compared with the 138 billion gallons of gasoline consumed annually by vehicles in the United States.

Producing advanced biofuels on the scale of tens of billions of gallons per year will mean financing several hundred commercial-scale biorefineries at a net cost of roughly $250 billion. For investors in cellulosic ethanol to get a fair return on their money, the cost of oil would have to rise to $90 (and possibly as much as $120) per barrel, according to a joint study by Sandia National Laboratory and General Motors. Short of that, government support will be required to promote investment, in the form of tax breaks and mandates of the sort included in the Energy Independence and Security Act of 2007, which calls for 36 billion gallons of renewable fuel to be incorporated into the annual U.S. fuel supply by 2022 *(see "Washington Backs Plug-ins," p. 67)*.

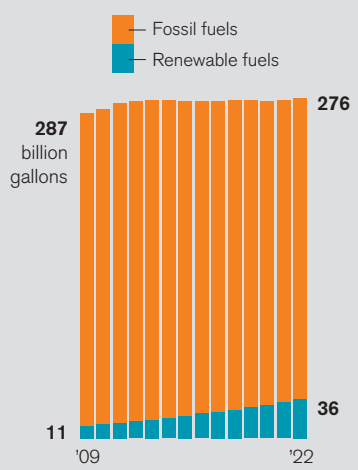
Makers of battery-powered vehicles also face problems in scaling up production. Mitsubishi began offering its electric subcompact to fleet customers in Japan this summer, GM plans to bring its Chevy Volt sedan to market in late 2010, and another half-dozen automakers and electric-vehicle developers plan to release battery vehicles of their own over the next two years *(see "Electric Cars Move Slowly," p. 68)*. But the high price of lithium-ion batteries, the leading technology for electric vehicles, may relegate all these cars to a niche market. Because of the 16 kilowatt-hours' worth of lithium-ion cells found in the Mitsubishi electric vehicle, the price of the car starts at 4.6 million yen (about $50,000), several times as much as an equivalent gas-powered subcompact costs.

Getting the price down might be difficult because of limitations inherent in the technology. Conventional lithium batteries rely on costly metals such as cobalt. And newer lithium–iron phosphate batteries use nanostructured materials whose synthesis is time-consuming and expensive. Government support will be required to help bridge the cost gap between electric vehicles and comparable internal-combustion vehicles. How long that support will be needed is unknown. *—Peter Fairley*

BIG OIL

Biofuels won't displace fossil fuels' dominance for the foreseeable future

**Projected U.S. consumption of liquid fossil and renewable fuels**
(billions of gallons)




*Sources: Environmental Protection Agency, EIA*

AVIATION

# Satellites for Speedy Skies

In 2007, 769 million passengers flew in the United States—a 72 percent increase over 20 years ago. But the world's radar-based air traffic control system, which hasn't changed much since the 1950s, is having difficulty keeping up. Around busy airports, controllers keep planes locked in constrained flight patterns with generous spacing margins for safety, because most radar systems "paint" planes only once every four seconds. These margins cause delays during bad weather or crowded conditions.

To add capacity, the United States is rolling out a new satellite-based air traffic control system, the key element of which is called Automatic Dependent Surveillance–Broadcast, or ADS-B. (Other nations are also beginning to adopt the technology.) By 2020, most

## UP, UP, AND AWAY

Congested airports haven't deterred passengers

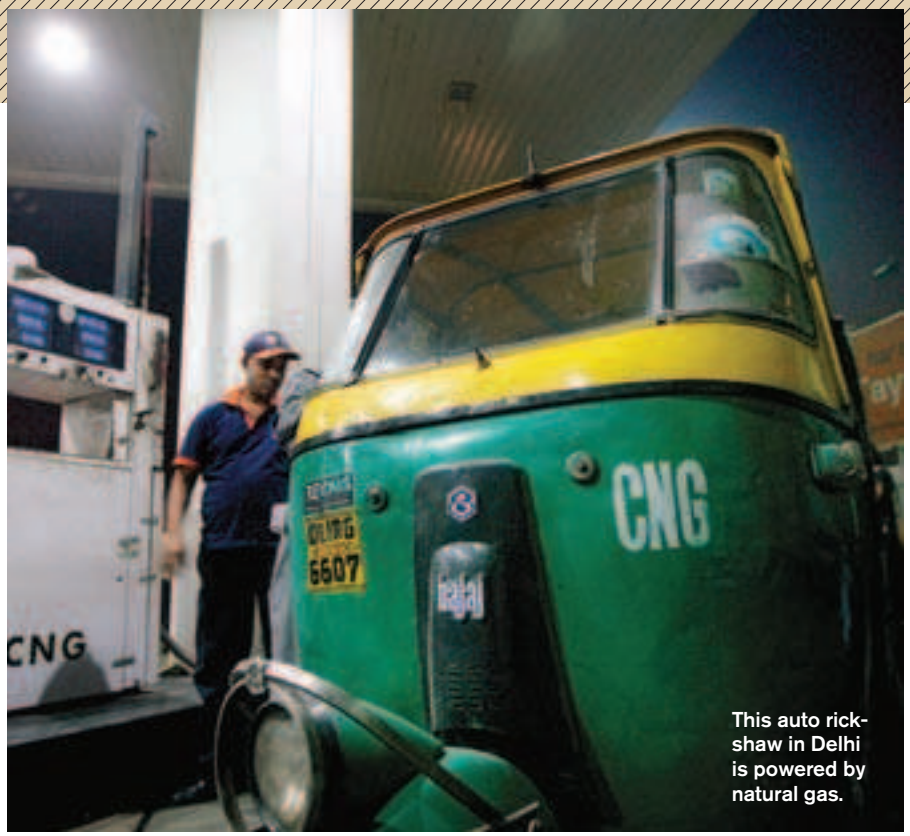

*Source: Bureau of Transportation Statistics*

planes will be required to carry a cockpit gadget that continuously broadcasts their GPS-derived location, altitude, and speed. Initially, this information will flow to ground-based controllers, allowing more precise instructions.

Eventually, all planes will also receive each other's position data. Onboard computers will let pilots chart course adjustments without having to consult air traffic control, and they will be able to fly closer together. "It will allow airplanes to line themselves up at the right spacing so controllers don't have to put in additional delays," says John Hansman, director of the International Center for Air Transportation at MIT.

The benefits will be even greater where there is no radar coverage, such as over the open ocean. Planes exiting radar coverage are now required to maintain a 60-mile gap, but with ADS-B in place, that distance can be reduced.

UPS has been testing ADS-B at its global hub in Louisville, KY, where about 100 planes converge during a three-hour period every night. There, ADS-B enabled the number of landings per hour to increase by as much as 15 percent, decreased emissions associated with landings and takeoffs by 34 percent, and reduced noise pollution by 30 percent. *—David Talbot*




This auto rickshaw in Delhi is powered by natural gas.

TAUSEEF MUSTAFA/AFP/GETTY IMAGES

ASIA-PACIFIC

# Cleaner Vehicles by the Million

Last January, for the first time, more cars were sold in China than in the United States. India's vehicle fleet is growing at a rate of 7 to 10 percent per year. Instead of attempting to reduce greenhouse-gas emissions with expensive technologies such as electric vehicles, low-income countries in the Asia-Pacific region are focused on improving existing internal-combustion engines.

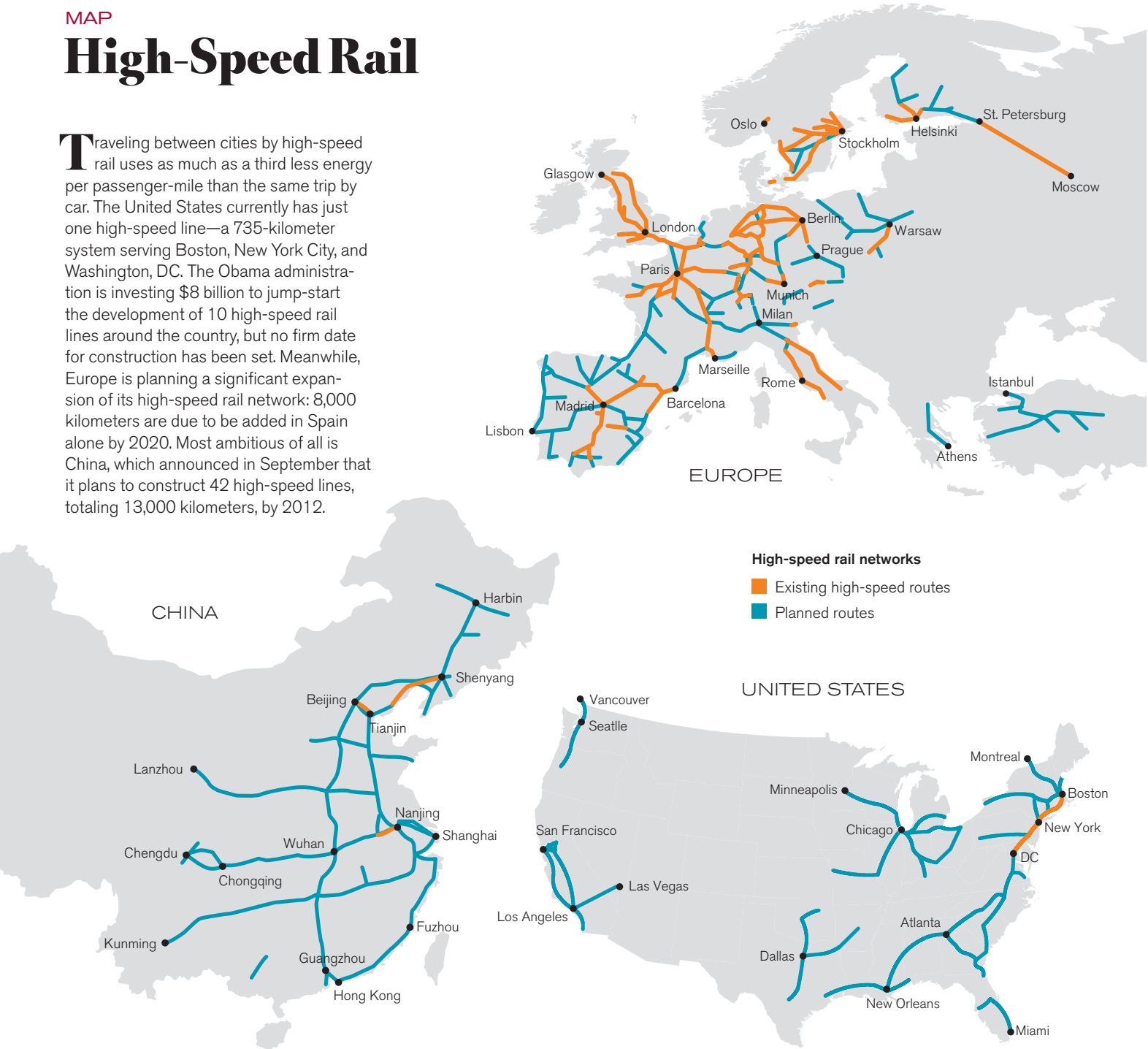
Converting cars to run on natural gas is an increasingly popular option. Of the 9.6 million natural-gas-fueled vehicles worldwide, 52 percent are in Asia-Pacific countries, with two million in Pakistan alone. A factory-built natural-gas vehicle can achieve reductions in carbon dioxide emissions as great as 25 percent, but most of the cars running on natural gas in this region are not quite as clean, because they have been converted from gasoline using after-market kits. Still, these converted vehicles emit half as much nitrous oxide as gasoline-fueled vehicles and three-quarters as much carbon monoxide. Conversion kits cost between $850 and $2,500, but conversion reduces driving costs because natural gas is cheaper than gasoline or diesel. The number of natural-gas vehicles has been growing at an annual rate of 40 percent over the last five years, according to the Asia Pacific Natural Gas Vehicles Association.

Asia is also home to more than 50 million vehicles powered by two-stroke engines, such as motorcycles and taxis. Per mile, each one produces as much in hydrocarbon and particulate emissions as 30 to 50 modern four-stroke automobiles, according to Bryan Willson, a professor of mechanical engineering at Colorado State University. The nonprofit Envirofit has developed a $300 fuel-injection kit that increases fuel efficiency by 35 percent and reduces hydrocarbon emissions by 89 percent. Owners can purchase the kit with microloans, and reduced fuel bills mean it pays for itself in six months. *—Susan Arterian Chang*

MAP

# High-Speed Rail

Traveling between cities by high-speed rail uses as much as a third less energy per passenger-mile than the same trip by car. The United States currently has just one high-speed line—a 735-kilometer system serving Boston, New York City, and Washington, DC. The Obama administration is investing $8 billion to jump-start the development of 10 high-speed rail lines around the country, but no firm date for construction has been set. Meanwhile, Europe is planning a significant expansion of its high-speed rail network: 8,000 kilometers are due to be added in Spain alone by 2020. Most ambitious of all is China, which announced in September that it plans to construct 42 high-speed lines, totaling 13,000 kilometers, by 2012.




London's congestion pricing began in 2003.

IMAGE SOURCE/CORBIS

OVER THE HORIZON

# Urban Renewal

More than half the world's population currently lives in urban areas. By 2050, 70 percent will do so. Finding ways to move these people around quickly and efficiently will be crucial in order to increase productivity and decrease the environmental impact of transportation.

Part of the solution will involve smarter traffic management for mass transit: opening and closing lanes to other vehicles and changing traffic lights as needed can help move buses and streetcars quickly. In one system already used in Zurich, streetcars "are very close to that magical goal of zero traffic delay," says Peter Furth, a professor of civil and environmental engineering at Northeastern University.

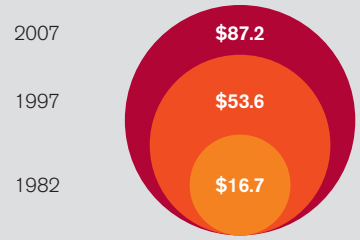
For cars, GPS-based systems will soon help drivers avoid traffic, rerouting them carefully to avoid causing new traffic jams elsewhere. Eventually, people will have to pay to drive in congested areas, especially if they're driving large, inefficient vehicles (current congestion pricing systems in London and other cities rely on cameras to identify license plates). That could promote the development of small electric vehicles that would be owned by city dwellers or rented at train stations to take commuters the last few kilometers to work.

Finally, increased use of automation will allow more motorists to share the roads. Already, some cars can park themselves or brake automatically to avoid accidents. In the future, automated cars will move smoothly through traffic at following distances too close for human reaction times, updating their routes as traffic patterns change and coördinating lane changes with other vehicles. *—Kevin Bullis*

## STUCK IN TRAFFIC

Getting snarled in congestion is not just inconvenient—it's expensive

**Cost of traffic congestion**
(billions of 2007 dollars)




*Source: Texas Transportation Institute*

## DATA SHOT

**45 BCE**

The year Julius Caesar introduced traffic congestion controls, banning private vehicles from the center of Rome between 6 A.M. and 4 P.M.

POLICY

# Washington Backs Plug-ins

By mandating that automakers build cars capable of traveling 35 miles per gallon by 2020 and that 36 billion gallons of the United States' transportation fuel come from renewable sources by 2022, the Energy Independence and Security Act of 2007 was intended to reduce the country's dependence on imported petroleum.

The recession "may buy us a couple more years," but rising fuel demand will soon wipe out any reductions arising from the legislation, says Kenneth Berlin, the author of several reports on energy security and global warming published by the Center for American Progress, a Washington-based think tank.

In an attempt to further reduce oil imports—and greenhouse-gas emissions—the Obama administration pledged $2.4 billion of stimulus funds last March to manufacturers of components for plug-in hybrids and those seeking to build charging stations and other infrastructure for electric vehicles.

Stimulus funds are intended to be a one-shoot boost. In the longer term, energy legislation currently before the U.S. Congress could spur the development of new transportation technologies, particularly electric vehicles. The House has already passed a bill mandating that electric utilities develop plans to support the use of plug-in hybrids (ideally, such plans would include public charging stations). The bill also offers financial supports to offset the higher cost of electric vehicles. The Senate version introduced in September similarly demands work on plug-in hybrids and charging stations, but it does not contain a specific provision for purchase offsets. *—Stephen Cass*

The all-electric Roadster from Tesla costs $109,000.

COURTESY OF TESLA MOTORS

MARKETWATCH

# Electric Cars Move Slowly

Some of the world's biggest automakers—Toyota, General Motors, Ford, Nissan-Renault—will begin building all-electric vehicles next year. In his presidential campaign, Barack Obama proposed putting one million plug-in vehicles on U.S. roads by 2015. But production numbers will be tiny for years. Even General Motors, notwithstanding all the publicity it received for its commitment to bring the Chevrolet Volt plug-in hybrid to market in 2011, plans to build only 10,000 Volts in 2011, and 60,000 in 2012. The consensus among industry analysts is that worldwide, fewer than one million of the 70 million vehicles manufactured annually will be electric-drive cars until at least 2015.

Boston Consulting Group further predicts that in 2020, under current trends, just one million plug-in vehicles will be sold in North America—roughly 5 percent of all vehicles. And market share is expected to stay in the low single digits until the cost per kilowatt-hour of lithium-ion batteries falls to a third or less of today's level of $500 to $900 *(see "Scaling Up Is Hard To Do," p. 64)*.

The growth path that conventional hybrids have followed may be a good indication of how the newer technologies are likely to play out. Conventional hybrids, which charge their batteries using a gasoline engine, took 10 years to garner 2.5 percent of the U.S. market and about 1 percent of the global market. They will probably represent 4 or 5 percent of global production, or three million vehicles, by 2015, and the automakers expected to be leaders are Toyota, Honda, Ford, GM, Hyundai, and Volkswagen. Sales of plug-in hybrids and battery-electric vehicles are likely to grow at a similar rate unless development is accelerated by aggressive subsidies or tax advantages to offset the high cost of their battery packs.

Electric-car startups could have a presence in the market. Tesla's all-electric Roadster, which can accelerate from 0 to 60 miles per hour in less than four seconds, is already for sale at $109,000, and Fisker's Karma plug-in hybrid luxury sports sedan, at $87,900, will be in drivers' hands by the middle of next year. But going beyond boutique production is a hard, hugely expensive challenge. Not since Chrysler was founded, in 1925, has a U.S. automotive startup grown into a major brand.

Meanwhile, electric cars will compete against gasoline and diesel engines that are growing ever more fuel-efficient. Between 2020 and 2030, midsize sedans may reach 40 to 50 miles per gallon thanks to much smaller engines, turbocharging and direct-injection technology, a 30 percent reduction in vehicle weight, and aerodynamic improvements *(see "Petroleum's Long Good-bye," p. 60)*. Whether they will cost less than an equivalent electric-drive car is the question facing the industry's planners today. *—John Voelcker*

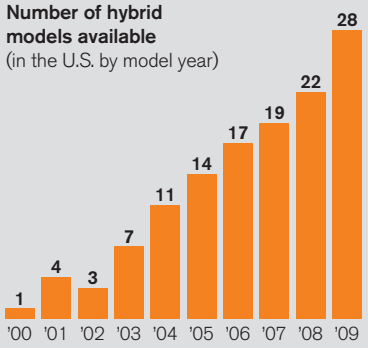
DATA SHOT

**44.4 MJ/kg**

The energy density of gasoline. Ethanol has an energy density of 26.9 MJ/kg, while lithium batteries have an energy density between 0.3 and 0.5 MJ/kg.

AN ELECTRIC TREND

Automakers are jumping on the hybrid bandwagon




*Source: FuelEconomy.gov*

MARKET TABLES

# Companies to Watch

## PRIVATE COMPANIES

| Company | Funding raised | |
|---|---|---|
| **Tesla Motors**<br>teslamotors.com<br>Year founded: 2003 | $278 million<br>Daimler, Valor Equity Partners, Technology Partners, Draper Fisher Jurvetson, DBL, Westly Group, Compass Venture Partners | This startup beat the major players to the punch by bringing the first highway-ready all-electric car to market, but the car remains a luxury item at more than $100,000. With a $456 million loan from the government, Tesla now hopes to introduce a more modestly priced electric sedan. |
| **EnerG2**<br>energ2.com<br>Year founded: 2003 | $11 million<br>OVP Venture Partners, Firelake Capital Management, Yaletown, WRF Capital | Recently received $21.3 million in stimulus funding to build a facility that will manufacture electrodes and other materials for ultracapacitors, which can store and release energy faster than batteries. Better ultracapacitors could enable carmakers to cut the size and cost of battery packs used in plug-in hybrid vehicles by as much as half. |
| **Synthetic Genomics**<br>syntheticgenomics.com<br>Year founded: 2005 | Undisclosed<br>Draper Fisher Jurvetson, BP, Meteor Group, Biotechonomy, Plenus, S.A. de C.V. | Founded by genomics pioneer J. Craig Venter, Synthetic Genomics has partnered with ExxonMobil and BP on projects that would use genetic engineering to make cheap, cleaner fuels from algae and coal-bed methane. |
| **Range Fuels**<br>rangefuels.com<br>Year founded: 2004 | Over $100 million<br>Passport Capital, BlueMountain, Khosla Ventures, Leaf Clean Energy Company, PCG Clean Energy & Technology Fund | Produces cellulosic ethanol using a thermochemical process that turns biomass into synthetic gas and then liquid fuel. The company is set to open the United States' first commercial cellulosic-ethanol plant in Georgia next year. |
| **Qteros**<br>qteros.com<br>Year founded: 2006 | $30 million<br>Battery Ventures, BP, Camros Capital, Long River Ventures, Quantum Group of Funds, Venrock, Valero | Uses a unique type of microbe to convert biomass into ethanol in one step, potentially replacing a multistep process that uses expensive enzymes to break down cellulose. |
| **Advanced Transport Systems**<br>atsltd.co.uk<br>Year founded: 1995 | Over $25 million<br>BAA | Spun out of the University of Bristol in 1995, the company is developing a personal rapid-transit system that uses less energy than other forms of mass transit. The first version of the technology is currently in operational testing at Heathrow Airport. |
| **Mascoma**<br>mascoma.com<br>Year founded: 2005 | $100 million<br>Khosla Ventures, Kleiner Perkins Caufield & Byers, Flagship Ventures, General Catalyst Partners, Marathon | Is commercializing a cheap one-step process for producing cellulosic ethanol, using specially developed yeasts and bacteria. Late last year the company started producing ethanol at a demonstration facility; it hopes to break ground on its first commercial production facility next year. |
| **Better Place**<br>betterplace.com<br>Year founded: 2007 | Over $300 million<br>VantagePoint Venture Partners, Israel Corporation, Israel Cleantech Ventures, Morgan Stanley, Acorns to Oaks II | Is building charging stations for electric vehicles worldwide and also hopes to open chains of battery-swapping stations, but this will require car companies to standardize their batteries. |
| **Fisker Automotive**<br>fiskerautomotive.com<br>Year founded: 2007 | Over $150 million<br>Palo Alto Ventures, Kleiner Perkins Caufield & Byers | With a half-billion-dollar loan from the U.S. Department of Energy recently secured, production of a luxury plug-in hybrid, the Karma, is expected to begin next year. The company is also working to bring a more affordable model to market. |
| **Systra Group**<br>systra.com<br>Year founded: 1995 | Funded by revenue<br>RATP Group, SCNF Group | Constructs subway and rail systems throughout the world—including what will be the world's largest automated light rail, currently under construction in Dubai. |

## PUBLIC COMPANIES

| Company | Global auto sales, 2008 | Market cap | |
|---|---|---|---|
| **Ford**<br>ford.com | 5.5 million | $23.6 billion | The only carmaker of the Big Three to avoid bankruptcy, Ford still lost nearly $15 billion last year. Promising to bring plug-in hybrids to showrooms in 2012, the company has also turned to Magna International to help it build an electric version of its popular Focus. |
| **General Motors**<br>gm.com | 8.4 million | N/A | Recently emerged from a bankruptcy reorganization, GM hopes its much-anticipated electric Volt, scheduled to reach customers in 2011, will help rehabilitate its image. |
| **A123 Systems**<br>A123systems.com | | $1.86 billion | Although it lost out to South Korean battery maker LG Chem in its bid to charge up the Chevy Volt, A123 recently struck a deal with Chrysler to provide the batteries for its ENVI line of electric vehicles, the first of which is expected to hit the market next year. A $250 million stimulus grant and a $378 million IPO signaled support from both the federal government and Wall Street. |
| **Toyota**<br>toyota.com | 9.0 million | $128.9 billion | The largest automaker in the world recently unveiled the third generation of its Prius hybrid. The company also announced that it plans to bring an all-electric vehicle to market by 2013. |
| **BYD Auto**<br>byd.com | 170,000 | $19.9 billion | Last year, Warren Buffett bought a stake in this Chinese carmaker, which sprung from a manufacturer of cell-phone batteries. The BYD F3DM, introduced in 2008, was the first mass-produced plug-in hybrid to hit the market. |
| **LG Chem**<br>lgchem.com | | $13.7 billion | With subsidiary Compact Power, this South Korean battery maker won the contract to provide power for the forthcoming Chevy Volt. The company plans to invest more than $800 million in a plant to manufacture batteries for electric vehicles. |
| **Johnson Controls**<br>johnsoncontrols.com | | $15.1 billion | Grabbing $300 million of the $2 billion in grants that the stimulus bill set aside for manufacturing advanced batteries, Johnson Controls is building a new facility in Holland, MI, to make lithium-ion batteries for hybrid and all-electric vehicles. |
| **Siemens**<br>siemens.com | | $80.9 billion | The German engineering giant designs and builds mass-transit systems around the world. The new Sapsan high-speed train that it developed for Russia will be a competitor for planned U.S. high-speed links. |
| **Daimler**<br>daimler.com | 2.1 million | $50.7 billion | Having ended its ill-fated marriage with Chrysler two years ago, Daimler can now focus on its Mercedes-Benz and Smart car lines. The company says it expects to commercialize a hydrogen-powered car by 2015. |
| **General Electric**<br>ge.com | | $176.2 billion | GE's transportation division provides $10 billion in revenues and nearly $1 billion in profits. The company has just unveiled what it claims is the most fuel-efficient rail locomotive, and it recently announced it would build a facility to manufacture batteries for hybrid locomotives. |

MARKET TABLES

# Research to Watch

| Project | Principal institutions | |
|---|---|---|
| **Next-generation internal-combustion engine** | General Motors/University of Michigan Collaborative Research Laboratories<br>gmcrl-esr.engin.umich.edu | New technology combining elements of spark ignition and diesel engines promises to be 15 percent more fuel-efficient than conventional gas engines. |
| **Active traffic management** | U.S. Department of Transportation<br>www.intellidriveusa.org/research/michigan-testbed.php | Wireless communication between vehicles and roadway infrastructure could reduce congestion by providing real-time information to drivers and traffic managers. |
| **Carbon-nanotube ultracapacitors** | MIT<br>lees.mit.edu/lees/ultracapacitors.htm | Advanced ultracapacitors for hybrid and electric cars would charge and discharge much faster than batteries. |
| **National Bus Rapid Transit Institute** | University of South Florida<br>www.nbrti.org | Is working to combine buses with intelligent transportation technologies to create systems that can substitute for light rail or subways in cities. |
| **Aviation biofuels** | Boeing<br>www.newairplane.com/environment/sustainablebiofuels | Different biofuels are being tested for use in commercial jets. |
| **The Civitas Initiative** | European Commission<br>www.civitas.eu | Is developing integrated technological and policy-based approaches to energy-efficient transportation in cities. |
| **Lithium-air batteries** | IBM<br>www.almaden.ibm.com | Technology that could store 10 times as much energy as conventional lithium batteries. |
| **Next-generation train** | German Aerospace Center<br>www.dlr.de | This new system would use half as much energy as other high-speed trains and be 25 percent faster. |
| **Energy Biosciences Institute** | University of California, Berkeley; Lawrence Berkeley National Laboratory; University of Illinois; BP<br>www.energybiosciencesinstitute.org | Plans to develop biofuels using synthetic biology. |
| **X-37B** | U.S. Air Force, Boeing | The first demonstration of an unmanned military space plane will take place in January 2010. In theory, a space plane could take passengers from London to Sydney in four to five hours. |

# REVIEWS

ENERGY

## Nuclear Power Renaissance?

DON'T BET ON IT. THIRTY YEARS AFTER THREE MILE ISLAND, NUCLEAR IS STILL TOO RISKY. BUT NOW THE RISKS HAVE SHIFTED FROM PHYSICAL TO FINANCIAL.

*By* MATTHEW L. WALD

Thirty years ago, in March 1979, a group of badly trained operators in the control room at Three Mile Island's unit 2 confronted a minor malfunction. The problem, a simple pump shutdown, was quickly made worse by an instrument panel that failed to inform the operators about a stuck valve and by an alarm system that overloaded after the first malfunction. The operators botched an attempt to solve the rapidly escalating problem, allowing a small leak to drain most of the cooling water out of the $700 million reactor. In about two hours, they converted America's newest nuclear plant, which had begun commercial operation just three months earlier, into a $1 billion liability.

**30TH ANNIVERSARY OF THE ACCIDENT AT THREE MILE ISLAND UNIT 2**

The event at the reactor, near Harrisburg, PA, provoked near-panic, and although government reports said the maximum possible radiation exposure was too small to have much effect on human health, one major casualty was the outlook for the nuclear industry itself. The meltdown did not end the first round of nuclear construction in this country; 50 reactors already under construction were completed after the accident, and orders for new plants had effectively ceased anyway. (The last order for a nuclear plant that was actually built came in 1973.) But for years to come, it remained unthinkable to plan new reactors as part of the nation's energy portfolio.

Given pressures to reduce carbon dioxide emissions from fossil-fuel power plants, however, construction of nuclear plants could be poised to begin anew. The technology has grown more reliable and more efficient. Reactors now run 90 percent of the hours in a year, compared with less than 60 percent in 1979, effectively cutting the capital cost of a kilowatt-hour by about a third. Meanwhile, other sources of power have started looking a lot worse. Congress seems likely to put some kind of price tag on carbon dioxide emissions, so the price of coal-produced electricity could rise by 30 to 50 percent. The price of natural gas is low right now but has been more volatile than the price of oil in the past few months as surging supplies and lackluster demand play leapfrog. Such volatility makes electric companies reluctant to rely heavily on gas.

All the same, the nuclear industry faces tremendous risks, though their nature has changed since 1979. As the possibility of an accident that panics or injures the neighbors has diminished, the likelihood has grown that even a properly functioning new reactor will be unable to pay for itself. And changes in the utility industry since 1979 mean that this time, the money a company wastes may be its own.

Whether new nuclear plants are a good bet economically depends on three factors, all now in flux. First is the cost of a new reactor. In 2005, a few would-be reactor builders said they could construct a facility generating 1.2 to 1.6 gigawatts for $2,000 per kilowatt of capacity. Now, they put the cost at $4,000 per kilowatt. Neither price includes interest charges accrued during construction, which could be substantial if the job takes more than the five years or so that the builders predict—or if interest rates rise, as they are expected to. The Electric Power Research Institute, a utility consortium based in Palo Alto, CA, recently put the capital cost of a new coal plant at under $3,000 per kilowatt and that of a natural-gas plant at $800 per kilowatt.

The second factor is uncertainty about possible future competitors. If 10 years from now wind or solar plants, or coal plants that capture their carbon emissions, are able to deliver vast amounts of cheap power, the market price of electricity will fall, and plant owners may never see enough revenue to meet their costs.

The third factor is uncertainty about the price of fossil fuels, particularly natural gas. In the last year, the fuel cost for a kilowatt-hour generated from natural gas has varied from about 2.3 cents to about 9 cents. If a federal cap-and-trade system or


SIGNING UP A year after the accident at Three Mile Island, protesters gathered at the site to mark the anniversary and to demand that the nuclear power plant shut down. The industry stopped planning and building new reactors for decades, but interest has lately revived.

WALLY MCNAMEE/CORBIS

a tax on carbon dioxide emissions is instituted, that is likely to add 0.5 to 1.5 cents per kilowatt-hour. Add in 2 cents or more to recover the cost of building the plant, and the price of gas-fired power could make nuclear power look very attractive—or really overpriced.

A power-producing company that bets on natural gas can choose the size of its wager: a 100-megawatt plant, or a 500-megawatt or 1,500-megawatt one. Conventional nuclear plants come in only one size: jumbo. Some power companies have proposed smaller plants, but costs for factors like labor and security are mostly insensitive to size, so these costs per kilowatt-hour rise as the plant shrinks. Costs for engineering and materials are also greater per kilowatt-hour the smaller the plant is.

All these economic risks matter for nuclear power now, because the electricity marketplace has changed dramatically since the industry was deregulated in the 1990s. Before that, each plant's output was paid for by consumers, no matter what the cost. As a result, millions of consumers got stuck paying more than they should have, because their local utilities unwisely chose nuclear instead of coal or natural gas. The financial rules differed from state to state, but generally, once a plant was in service, a company could collect a specified return on its investment, and if a plant projected to cost $1 billion ended up costing $2 billion, the customers paid.

In today's electricity market, however, producers in many states are paid according to market price. Companies build a plant for whatever price they can manage and sell electricity for whatever price they can get. If a reactor produces power at 10 cents per kilowatt-hour and a natural-gas plant produces it at 12 cents, the reactor builder makes a killing. Reverse the numbers and the reactor builder gets killed.

The electricity industry won't build much of anything these days without government help, in the form of loan guarantees, production tax credits, guaranteed markets, or, preferably, all three. Wind now gets bigger production subsidies than nuclear on every kilowatt-hour generated, proportionally more loan guarantees, and a guaranteed market: many states insist on a certain quota of renewable energy, sometimes regardless of cost. In contrast, nuclear power receives production subsidies on only the first 6,000 megawatts of capacity (four or five reactors' output), and its pool of loan guarantees is shrinking relative to the price of construction.

"Right now, the federal incentives are much more conducive to pushing forward renewables," said Jim Miller, the chief executive of the energy company PPL, in June. His company, based in Allentown, PA, would like to build a reactor but will not do so without federal loan guarantees. It will not get them, at least not under the 2005 Energy Policy Act, in which Congress approved only enough to assist a handful

of plants: $18.5 billion. "Nothing is currently in place to move the nuclear industry along at the pace people perceived it would move when the 2005 act was passed," Miller says.

The idea of the legislation was that Congress would spoon-feed financial aid to the first half-dozen or so new nuclear plants, and others would follow on their own once new designs were demonstrated and a reformed licensing process was in place. Now, it looks as if those half-dozen new reactors will be the limit of the "renaissance," unless more help is forthcoming. The industry lacks the votes in Congress to expand the loan-guarantee program. Subsidies for wind and solar power are popular, in part because they can be justified as aid to emerging technologies. But many legislators feel that nuclear is less deserving of taxpayer support.

THE ELECTRICITY INDUSTRY WON'T BUILD MUCH OF ANYTHING THESE DAYS WITHOUT GOVERNMENT HELP, IN THE FORM OF LOAN GUARANTEES, PRODUCTION TAX CREDITS, GUARANTEED MARKETS, OR, PREFERABLY, ALL THREE.

Even now, nuclear power has the potential to be economically attractive if costs and competition are favorable—and if overall demand for power remain strong, with high industrial use and limited improvements in efficiency.

All of that is possible. But the odds are probably not good enough for the nuclear industry to place a bet with its own money. Only the government can agree to back up that bet, and it has yet to do so. TR

MATTHEW L. WALD IS A REPORTER AT THE *NEW YORK TIMES*. HIS FEATURE "THE BEST NUCLEAR OPTION" APPEARED IN THE JULY/AUGUST 2006 ISSUE OF *TECHNOLOGY REVIEW*.

MEDICINE

# Green Genes

THE FIRST TRANSGENIC PRIMATES ABLE TO PASS ON THEIR FOREIGN GENES ARE BOTH A STUNNING MEDICAL ADVANCE AND A TROUBLING PEEK INTO THE FUTURE.

*By* AMANDA SCHAFFER

This spring, news of a biological breakthrough arrived in the form of baby marmosets whose feet glowed green under ultraviolet light. Researchers at the Central Institute for Experimental Animals in Kawasaki, Japan, had genetically engineered the monkeys to incorporate a gene, derived from jellyfish, that produces green fluorescent protein. It was the first time scientists had added a gene to a primate in such a way that a new trait could be passed to a second generation.

**TRANSGENIC MONKEYS**

The feat heralds an exciting possibility: if the genes associated with some cases of human illnesses such as Huntington's disease, Parkinson's disease, amyotrophic lateral sclerosis (ALS), and Alzheimer's disease were introduced into primates, colonies of the genetically altered animals could be used to test therapies for these disorders. This would probably be far more effective than studying the effects of the genes in, say, mice or rats, because primates' brains are much closer to humans' in terms of complex motor functions and cognition. "We've been waiting a long time for [disease] models like these," says John Morrison, a professor of neuroscience at Mount Sinai School of Medicine in New York.

For years, researchers have created animal models for the study of disease by transferring new genes into less advanced animals such as mice. In 2001, scientists at Oregon Health and Science University reported the first transgenic primate, a rhesus monkey that produced green fluorescent protein. But the Japanese researchers broke new ground. Erika Sasaki and her colleagues introduced the jellyfish gene into early-stage marmoset embryos. Then they transplanted the embryos into adult female monkeys, resulting in several pregnancies and a few offspring that carried the gene. Sperm and egg cells from monkeys with the gene were then used to produce additional offspring in vitro, some of which also carried the gene and produced the fluorescent protein.

Of course, creating a few transgenic marmosets is a long way from creating colonies available for testing disease-specific treatments. For one thing, Sasaki and her colleagues used a virus to introduce the new gene, which means that they could not control how many copies would be inserted into the monkeys' genome or exactly where they would be incorporated. Researchers will probably need to develop a more precise, consistent way to introduce new genes, especially if they want to simulate diseases.

Besides, marmosets may not be an ideal research model. They were a good choice for the Japanese team because they reach sexual maturity relatively quickly, and females may produce 40 to 80 offspring in a lifetime. They're also less expensive and more efficient to work with at the colony level than larger primates that reproduce less copiously. Still, they have yet to prove themselves as models for neurodegenerative diseases. That's because their brains differ more from humans' than the brains of Old World monkeys like rhesus macaques do. And less is known about their normal cognitive function, because it has not been studied as actively. So for studying disruptions of higher-order processes like memory, which can be central to neurodegenerative diseases such as Alzheimer's, they may not be good enough.

CHRIS BUZELLI

Still, the possibility of transgenic primate models could revolutionize medical research. Such primates could offer a proving ground for new therapies that look promising in mice but seem too risky to try in humans. This is especially true for disorders that involve the brain and nervous system. Morrison says the lack of good primate models has been a "major obstacle" in developing and testing new treatments for several neurodegenerative diseases.

Huntington's disease is a case in point. Current rodent models do not capture key aspects of the disorder, in part because of differences between their brains and those of humans. People with Huntington's typically display abnormal movement, especially the writhing movements called chorea; they also tend to develop dementia or even psychosis. But rodents don't have the types of neurons, the number of synapses, or the types of neural relay centers that are crucial to human motor control, so researchers can't see exactly how potential treatments will affect these systems. A team led by Steve Goldman, a professor of neurology and neurosurgery at the University of Rochester Medical Center, has developed a possible therapy that uses stem cells to regenerate a type of neuron lost in Huntington's disease. It works in mice, he says. But it's not something that's going to be tested in humans until the researchers can try it out in primates first, because the relevant anatomy in mice is just too different.

Transgenic primates could also prove extremely helpful as disease models for ALS and Alzheimer's. By using them instead of mice, Morrison predicts, "we'd get a much more faithful model of the degeneration you see in humans." For instance, efforts to develop antibodies against amyloids—protein deposits that typically develop in the brains of Alzheimer's patients—seemed promising in mice but failed in humans. "My guess is that if we'd had a really good primate intermediate, we would've been better informed," he says.

To be sure, creating transgenic primates raises tricky ethical issues, especially if the new genes come from humans. The concern is that researchers might challenge the boundaries between humans and other species by inadvertently creating an animal with cognitive abilities such as rational thinking or moral reflection—a creature that would necessarily deserve a greater degree of respect than a typical lab animal, says Robert Streiffer, a bioethicist at the University of Wisconsin at Madison. The idea of experimenting on such an animal would probably strike both researchers and the public as unacceptable.

That situation seems like a distant possibility at the moment, Streiffer says. Still, monkeying with the germlines of primates does cross a new line and deserves careful scrutiny. For one thing, it could open the door to similar engineering in humans. Historically, ethicists have distinguished between introducing new genes into tissues like the liver or pancreas and altering egg cells, sperm cells, or embryos; the latter type of modification, which could be passed on to a recipient's offspring, has not been performed in humans. Critics typically point to the more frivolous possibilities—say, parents who might wish to give future generations a gene for strength or height. Still, when it comes to some serious diseases like Huntington's or certain mitochondrial disorders, germline genetic treatment could turn out to be the best or even the only option. "Are we willing to delay the possible discovery of treatments for terrible illnesses because we want to draw a line in the sand?" asks Mark Rothstein, a bioethicist at the University of Louisville. "I'm not willing to do that."

It is worth keeping in mind that these disorders are devastating. And for the most part, they are currently untreatable. Given that reality, the promise represented by the baby marmosets should be given ample opportunity to grow up. TR

AMANDA SCHAFFER IS A SCIENCE AND MEDICAL COLUMNIST FOR *SLATE* AND A CONTRIBUTOR TO THE *NEW YORK TIMES*.

THE WEB

# A Note on the Type

FONT DESIGNERS IMAGINE A BETTER-LOOKING WEB.

*By* JOSHUA J. FRIEDMAN

Compared with the world of print, the Web is a typographically impoverished place. It was built to display the fonts that users already have loaded on their computers, which in practice means the 10 "core fonts for the Web" that Microsoft started bundling with its Windows operating system in 1996. A few of these fonts are admirable—Verdana and Georgia, for example, which were designed by Matthew Carter specifically for the computer screen. But as the Web grows more sophisticated, and as the need to improve on-screen legibility becomes more urgent, they are far from sufficient.

You may not have noticed the problem—in part because the Web is filled with flashy headlines and logos, which can be more visually diverse because designers display them as images. But significantly absent are the workhorse text faces that occupied the great type designers of the past five centuries, like Garamond, Caslon, and Baskerville. These typefaces were sturdy and legible, graced with small but essential touches that elicit a curious passion in designers and laypeople alike. Fonts speak to people, probably because they give form to their written words. People brag about their favorite font and complain about the awful one their boss makes them use. Corporations are believers, too: they regularly commission expensive new fonts to lend flattering associations to their brands, and they wish they could do the same online.

Web designers and type designers have been planning a better future for at least 11 years, ever since the technical foundation was laid for browsers to load fonts stored on remote servers rather than on a computer's own hard drive. For the first time, this prospect feels tantalizingly close. As of this past June, with the release of Mozilla Firefox 3.5, all the major browsers finally support what's called the @font-face rule, a way to use the Cascading Style Sheets language to designate a remote font. As designers try to develop a format that delivers the fonts efficiently and securely, visions of the future are taking shape. The question of which will be realized was debated at this summer's TypeCon, a conference of type and graphic designers. The answer will be determined by decisions made over the coming months by browser makers, type designers, and Web designers, some in their capacity as representatives to the Web's international standards organization, the W3C.

**EMBEDDED OPENTYPE (EOT) FONT FORMAT**
www.w3.org/Submission/EOT

**WOFF FONT FORMAT**
people.mozilla.com/~jkew/woff/woff-spec-latest.html

**TYPEKIT**
blog.typekit.com

In one possible scenario, history repeats itself and we still don't get new fonts on the Web. Twelve years ago, Microsoft released a format—called Embedded OpenType, or EOT—that was meant to launch the Web-font era. EOT, which was developed to embed fonts in Microsoft Office documents, worked as a "wrapper" for desktop font files. It compressed them for downloading, included instructions about how they might legally be used, and allowed for the fonts to be encrypted. But Netscape, then a formidable competitor to Microsoft's Internet Explorer, chose a different format, leaving graphic designers with the choice of designing two versions of every Web page or leaving well enough alone. Web fonts never arrived.

Today, Microsoft is again promoting EOT at a time when its competitors have chosen another route. There would be two significant advantages to establishing EOT as the standard: first, the provisions for protecting and optimizing fonts, and second, the potential for swift change. Any solution that works immediately in Internet Explorer could eliminate years of waiting; IE users still represent about 65 percent of the market, and they take significantly longer to upgrade than users of other browsers. (Some are big corporations with conservative upgrade policies.) Microsoft has tried to answer objections from open-source advocates, including its largest competitor, Mozilla, by opening up the proprietary components of EOT. But with no sign so far that other browser makers are willing to adopt Microsoft's standard and thus extend its dominance, a format impasse could spell another long dry period for Web fonts.

All the browsers but Microsoft's, meanwhile, have embraced a technique called "naked" or "raw" font linking, which means uploading ordinary desktop fonts onto servers. What if Microsoft, in the interest of guarding its diminishing share of the browser market, abandoned EOT in favor of this standard? Though it would take a few years for IE users to upgrade, soon enough the Web would be typographically transformed. But at a cost: in this new world, fonts would have no protection from piracy. After all, when your browser downloads a remote font onto your computer for temporary use (as it would have to), that font functions like any other on your hard drive. Who could blame you for thinking it was your property, no matter what the license might say?

Open-source advocates are not particularly worried about this scenario; they see piracy as a challenge that can be addressed through legal action and educational campaigns. But type designers see a world of raw fonts as a nightmare that could do to them what file sharing did to the music indus-

WWW See the @font-face rule in action, displaying this article with Web fonts: **technologyreview.com/fonts**

try. "You're throwing up a desktop font on a Web server, and there's no inherent protection for the font there," Thomas Phinney, formerly of Adobe's type group, said at TypeCon. "Unsurprisingly, this is freaking scary to type foundries." They could dig in their heels and write licenses that forbid using their fonts on the Web, but the price of sitting out the Web-font revolution would probably be too high to accept.

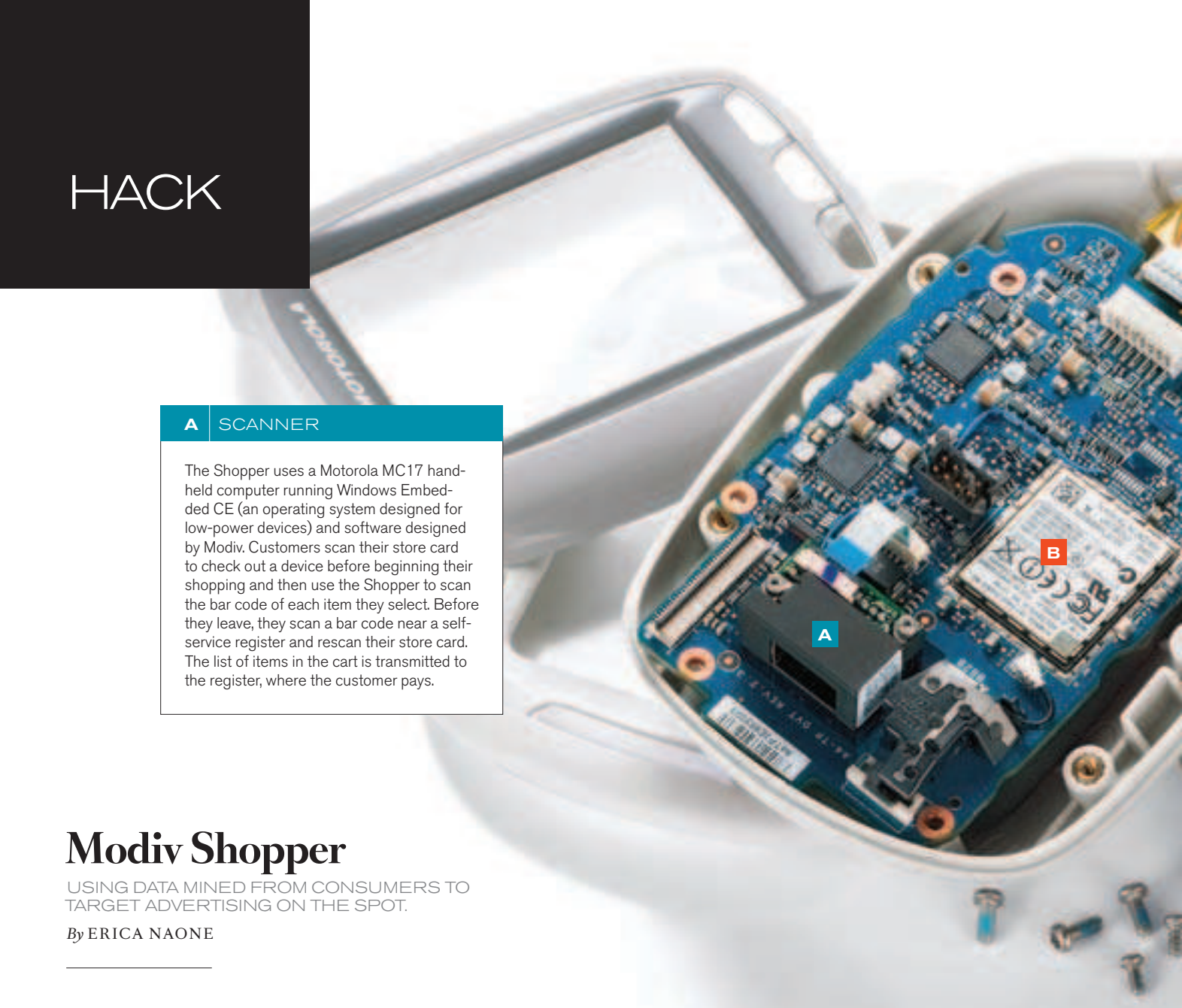
With a bit more patience, though, a third option could emerge—one that type designers see as ideal. Faced with the limitations of EOT and the risks of raw font linking, type designers and software engineers have been compiling a wish list for a brand-new, built-from-scratch font format. This system would offer better file compression to accommodate low-memory environments like mobile phones, and it would have a flexible metadata structure to embed information about permissions, but without turning browsers into enforcers.

Such a format has actually been created: Web Open Font Format, or WOFF, the combined work of the type designers Tal Leming and Erik van Blokland and Mozilla's Jonathan Kew. A petition supporting WOFF began circulating in July, and several dozen type foundries, including important ones such as Carter & Cone and Hoefler & Frere-Jones, have signed. Mozilla and others are already testing code for WOFF (and also a less ambitious but backward-compatible format called EOT Lite). This option seems like the best hope for type designers, but since it might take time for all the browsers to implement it and for users to upgrade, it depends on the Web community's patience.

While it remains to be seen if this ideal can be achieved, a startup called Small Batch is poised to launch an alternative with a service called Typekit. Small Batch (and also the startup Kernest) is offering to be a middleman: it would look after security issues for type designers and browser-compatibility issues for Web designers, who—instead of linking to fonts directly—would use JavaScript to link to Typekit. The company would create a new business model, transforming fonts from goods into a service. Rather than buying a font once and being able to use it indefinitely, Web designers (or their clients) would pay a recurring fee to buy access to one or more fonts in a library. (Typekit does offer some free fonts, too.) Users would lose access to the fonts when they stopped paying, but no fonts are really forever, anyway: formats change and type designers make improvements. In the service model, those improvements would be made along the way. Not only would fonts be kept up to date, but they'd be kept compatible with evolving platforms in an ever-changing browser market. "Until there's one format, one browser, and one operating system, there's a lot we can do to help," says Bryan Mason, one of Small Batch's founders.


Finding a solution that balances protection and freedom could redeem the missteps of a generation ago, when U.S. copyright law declined to cover typeface designs. The argument at the time was that protecting them would stifle innovation by concentrating the most popular designs in the hands of a few major foundries. But in effect, this decision permitted rampant plagiarism and thus removed the incentive to invest in type development. "We lost several decades in which corporate research could have contributed to our understanding of typographic legibility, aesthetics, and ergonomics," says Charles Bigelow, a distinguished type historian at Rochester Institute of Technology and one of the designers of the Mac OS X system font, Lucida Grande. Now copyright protection has been extended to fonts as software, and type design has made significant advances—for example, the text-rendering technology ClearType, a result of Microsoft's support for research into legibility. Bringing more fonts to the Web could lead to further progress. One prominent champion of Web fonts, Håkon Wium Lie, described the significance to me this way: "Archeologists of the future will classify Web pages into pre-font and post-font eras." TR

JOSHUA J. FRIEDMAN, A FORMER EDITOR AT THE *ATLANTIC* AND *BOSTON REVIEW*, IS A WRITER BASED IN NEW YORK CITY.




**A** SCANNER

The Shopper uses a Motorola MC17 handheld computer running Windows Embedded CE (an operating system designed for low-power devices) and software designed by Modiv. Customers scan their store card to check out a device before beginning their shopping and then use the Shopper to scan the bar code of each item they select. Before they leave, they scan a bar code near a self-service register and rescan their store card. The list of items in the cart is transmitted to the register, where the customer pays.

# Modiv Shopper

USING DATA MINED FROM CONSUMERS TO TARGET ADVERTISING ON THE SPOT.

*By* ERICA NAONE

GROCERY STORES in the United States and elsewhere have gotten customers used to carrying "loyalty cards" that track their shopping habits in exchange for in-store discounts. The Modiv Shopper, made by Modiv Media of Quincy, MA, takes things one step further. Customers using the device, which works with the store card, can save time by scanning and bagging their own groceries as they shop. Meanwhile, it displays advertising and offers electronic coupons for instant savings, all chosen according to the customer's purchasing history and location in the store. Introduced in July 2007, the Modiv Shopper is now used in 260 stores. The company says customers who use it spend $7 more per trip—and visit the store 10 percent more often—than they would otherwise. Modiv makes its money by licensing and developing its system for retailers and by collecting advertising revenue whenever an offer is displayed.

**B** RADIO MODULE

A radio chip inside the Shopper communicates with Wi-Fi hot spots around the store, triangulating with them to orient itself. (Wi-Fi is more reliable than GPS indoors.) By creating an internal map of the locations where the scanned items are stocked, the device is able to deliver coupons at appropriate points in a shopping trip.

CHRISTOPHER HARTING


## C BROWSER APPLICATION

Wi-Fi radio enables the device not only to deduce its location but also to receive data stored on central servers in the store. The customer interacts with the device through a Web application built by Modiv.

## D DISPLAY

A full-color LCD display allows customers to scroll through a list of items currently in the cart and to view coupons and advertisements for nearby items on the shelf.

## E DATA MINING

Each time customers use their store card, information is collected about the shopping trip. Modiv uses the aggregate data to spot shopping trends, and it uses the specific data to tailor promotions to the individual shopper. For example, a soda company might offer coupons to someone who normally buys from its competitor. Other offers might be triggered in real time by a customer's actions. Scanning a pack of hot dogs, say, might prompt a coupon for buns.

# Mining Fool's Gold for Solar

CYRUS WADIA IS USING ABUNDANT MATERIALS TO GROW NANOCRYSTALS FOR CHEAPER PHOTOVOLTAICS.

*By* KATHERINE BOURZAC

JEN SISKA

Fool's gold, also called pyrite or iron sulfide, can be unearthed just about anywhere, from the hills of California to the villages of Yunnan Province in China. But instead of digging pyrite up, researcher Cyrus Wadia is making pure nanoparticles of the compound from iron and sulfur salts in his lab at the University of California, Berkeley. His ultimate goal is to turn fool's gold into real treasure: an inexpensive solar cell.

Today, most solar cells are made of silicon, but they are expensive: though silicon is abundant, turning it into photovoltaics requires extensive, energy-intensive processing. Materials such as cadmium telluride and copper indium gallium diselenide are simpler to process, yielding thin-film cells that cost less to produce. But the elements needed to make these compounds, such as tellurium and gallium, are too rare to meet global energy demands.

So Wadia did a study of possible solar-cell materials, examining not only their chemistry and physics but also their availability. One of the standouts was fool's gold: it is abundant and cheap, and it has optical properties that allow it to efficiently convert sunlight into electricity. "The theoretical efficiency of iron sulfide is 31 percent. That's as good as silicon," says Wadia. What's more, 20 nanometers of pyrite can absorb as much light as 300 micrometers of silicon. Because it absorbs so much more light, it can be made into thinner cells, which require less raw material.

Matthew Beard, a senior scientist at the National Renewable Energy Laboratory in Golden, CO, thinks that Wadia and his colleagues "present a compelling case for pursuing these materials." Although the rarity of the elements used in newer thin films isn't currently an issue, it will be one in the long term, Beard says. Meanwhile, they pose a more immediate problem: some of them are toxic. These drawbacks make alternatives such as pyrite worth developing.

Previous efforts to build solar cells with pyrite produced devices that, at best, converted only 2.8 percent of sunlight into electricity. Wadia thinks the low efficiency is due to inconsistencies in the crystal structure of the pyrite. He is the first to make pyrite nanoparticles, and his method results in pyrite crystals with a uniform, favorable structure. The resulting material, he believes, will outperform conventional pyrite in solar cells.

## CRYSTALLINE CREATIONS

Pyrite's crystal structure can take several forms. Only one of them has the electrical properties that make pyrite a good solar material, though, and it takes just the right pH and temperature to generate a solution of nanocrystals that exist solely in that form. To make the crystals, Wadia pipettes chalky-orange iron salts, clear sulfide salts, and a bubbly, iridescent surfactant into a Teflon-lined metal cylinder. The surfactant keeps the particles from clumping as they grow. He seals the cylinder inside an autoclave container and bakes it at 200 °C for four hours. After he takes it out, Wadia unscrews the canister, revealing a clear liq-


1

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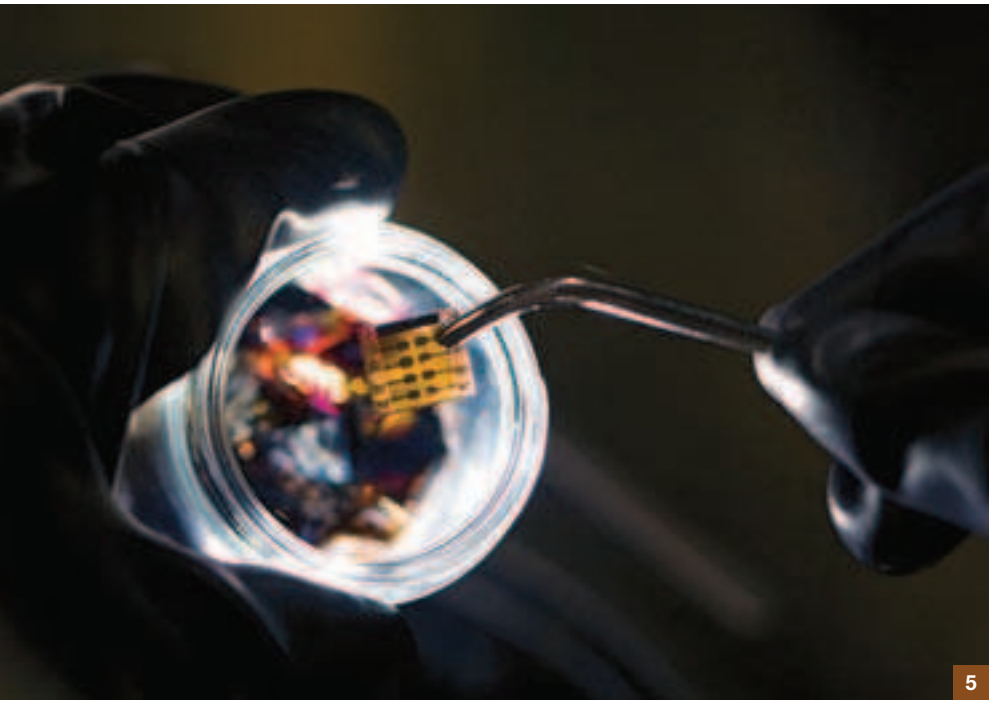
**Top left:** Cyrus Wadia makes pure pyrite nanocrystals in his lab at the University of California, Berkeley.
**1.** Iron salts are mixed with sulfide salts inside the metal autoclave container at left and heated in an oven for four hours.
**2.** The result: a black suspension of pyrite nanocrystals.
**3.** Wadia sets a glass chip on the circular pedestal in the center of a spin-coating machine and then drips the pyrite suspension onto it. A minute of spinning coats the chip with a thin film of pyrite.
**4.** He uses tweezers to set the chip on a hot plate; 10 to 15 minutes of heat will fix the nanocrystals to the surface.

uid with a black layer at the bottom: pure pyrite nanocrystals about 100 to 500 nanometers across.

To convert sunlight into usable electricity, solar cells require two different types of semiconductors. When photons hit the iron sulfide, electrons in the compound are excited—but those negative charges can't flow out of the cell and into an external circuit unless a compound with different electrical properties pulls away the positive charges, called holes. One candidate for the job is copper sulfide, another cheap and abundant material that Wadia has made into nanocrystals in collaboration with Yue Wu, now an assistant professor of chemical engineering at Purdue University.

Wadia synthesizes the nanocrystals of copper sulfide by injecting copper and sulfide salts and a surfactant into a three-neck flask over a hot plate; as a magnetic stir bar spins inside, nanoparticles of the compound form. After removing the surfactant and resuspending the nanoparticles in chloroform, he transfers them into a glove box. Inside is a glass chip, about 2.5 centimeters square, that has been coated with a thin layer of indium tin oxide, which acts as an electrical contact. Wadia places the glass chip on a small disc and pipettes the



**5.** Wadia places a glass chip with eight pyrite solar cells on its surface inside a solar simulator. The aluminum lines are the cells' top electrical contacts; the line across the top of the chip is a strip of conductive indium tin oxide.
**6.** Inside the solar simulator, the chip is illuminated with light in a mixture of wavelengths simulating the distribution found in sunlight. Electrical connections to the manifold read the current and voltage across each cell, helping Wadia to calculate its efficiency.

inky black suspension of pyrite nanocrystals onto it. He starts the disc spinning rapidly for a minute to spread the nanocrystals in an even layer. Then he sets the chip on a hot plate and heats it for 10 to 15 minutes to fix the particles to its surface.

After Wadia repeats the process with the copper sulfide solution, the bottom electrical contact is covered by the nanoparticle layers. He gives the chip a quick swipe with a plain cotton swab to reëxpose a strip of the indium tin oxide that acts as the bottom electrical contact for the cell. He then covers the chip with a mask, or stencil, that outlines two sets of four squares with rectangular tails. Wadia places the chip and a small piece of solid aluminum inside a thermal evaporator that looks like a metal bell jar. After he seals the jar, he heats it; the aluminum evaporates, and as it cools, it settles on the exposed parts of the chip. This creates eight square electrical contacts with tails that lead to the edge of the chip.

### PYRITE SEES THE LIGHT

The chip is now ready for testing. Wadia unscrews a solar-cell tester, places the chip inside, and screws it back together. He then illuminates it with light that mimics the distribution of wavelengths found in sunlight. When the light hits the chip, the system measures the current, the voltage across the chip, and other properties. A screen displays a plot of the current running through the cell against the voltage running across it. So far, the pyrite-based cells have proved disappointing in their performance, though the Berkeley researchers have used copper sulfide in combination with cadmium sulfide to make cells that have a 1.6 percent efficiency. That's not good enough for practical use, but the results are promising enough to justify continuing work on the technology.

Cells incorporating pyrite would be preferable because the material is less toxic and cheaper to recover than cadmium compounds. When the pyrite nanoparticles are spun onto the chip, however, nanoscale pinholes tend to form. To electrons, such minuscule gaps look like the Grand Canyon—they cannot cross and migrate into the external electrical circuit. Instead, the electrons tunnel down to the bottom electrode, causing the cell to short-circuit.

It's difficult to make good pyrite films because the nanocrystals tend to sink to the bottom of any liquid. The better a particle is suspended, the smoother the film it will form. Wadia believes that smaller particles might lead to better suspensions: the pyrite particles are 20 to 100 times the size of the copper sulfide particles, which are about five nanometers across. Wadia is trying everything he can to make them smaller, including mechanically pressing or grinding them and tinkering with reaction conditions. He's also collaborating with bioengineers at the Lawrence Berkeley National Laboratory to genetically engineer viruses so that they accumulate pyrite nanoparticles on their coats; the next step would be to get the viruses to line up into uniform films.

Wadia acknowledges that he's still many years away from making an efficient solar cell with pyrite nanocrystals. Ultimately, though, his goal is to produce a cell that's cheap enough to make solar energy the dominant power source. He says, "I just need the science to work." TR

www Watch a video of Cyrus Wadia making solar cells from fool's gold: **technologyreview.com/demo**

JEN SISKA

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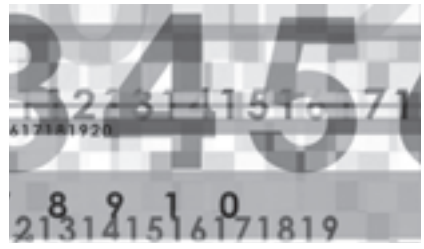

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Arthur T. Benjamin is Professor of Mathematics at Harvey Mudd College, where he has taught since 1989. He earned a Ph.D. in Mathematical Sciences from Johns Hopkins University. The Mathematical Association of America honored him with national awards for distinguished teachingin 1999 and 2000 and named him the George Pólya Lecturer for 2006–08.

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# FROM THE LABS

BIOMEDICINE

## Mice from Skin Cells

REPROGRAMMED CELLS DEVELOP INTO LIVE ANIMALS

**SOURCE: "IPS CELLS PRODUCE VIABLE MICE THROUGH TETRAPLOID COMPLEMENTATION"**
Qi Zhou et al.
*Nature* 461: 86–90

**"IPS CELLS CAN SUPPORT FULL-TERM DEVELOPMENT OF TETRAPLOID BLASTOCYST-COMPLEMENTED EMBRYOS"**
Shaorong Gao et al.
*Cell Stem Cell* 5: 135–138

**Results:** Researchers in China grew viable mice from induced pluripotent stem cells, which are made by modifying adult cells. Some of the mice went on to produce a second generation of offspring.

**Why it matters:** The research proved that induced pluripotent stem (iPS) cells, like embryonic stem cells, can differentiate into any cell type in the body. It suggests that iPS cells can be used for the same scientific purposes as embryonic stem cells—for example, to develop treatments that replace diseased cells.

**Methods:** Researchers transferred iPS cells generated from mouse fibroblasts (a type of skin cell) into specialized embryos that lacked the ability to develop on their own. Introducing the iPS cells triggered the embryos to begin developing. The embryos were then transplanted into surrogate mothers.

**Next steps:** Although the scientists' achievement was impressive, only 1 to 3 percent of the embryos developed into live mice. In addition, many of those mice had physical abnormalities or died soon after birth. Scientists want to understand how the differences between iPS cells and embryonic stem cells might lead to these abnormalities. They also want to increase the rate of live births.

A SPECIAL MOUSE This rodent grew from an embryo made with induced pluripotent stem cells, which were derived from adult skin cells.

QI ZHOU AND ZHUOLI

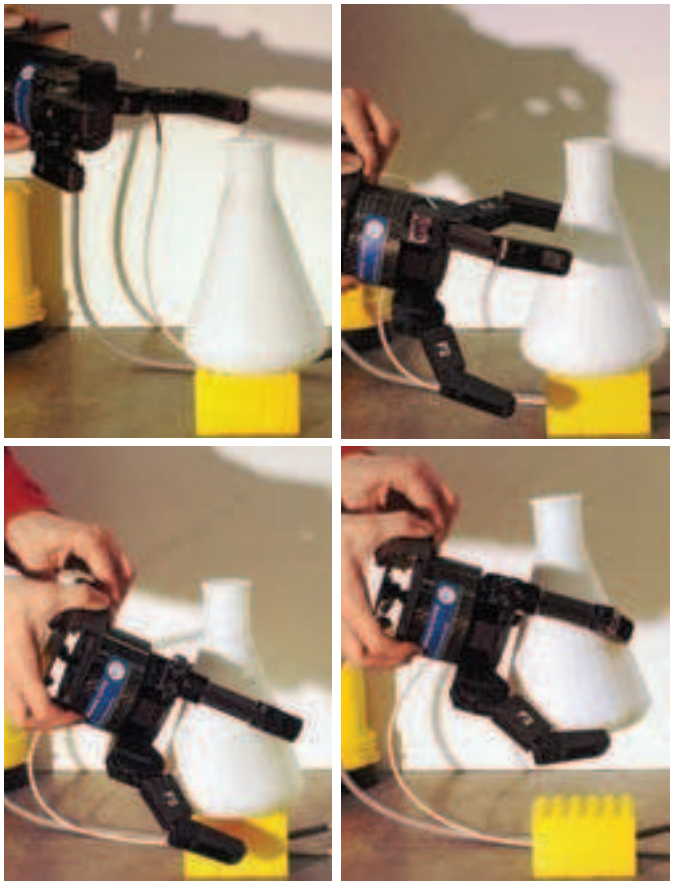
## Speedy Engineering

A MACHINE RAPIDLY MODIFIES BACTERIAL GENOMES

**SOURCE: "PROGRAMMING CELLS BY MULTIPLEX GENOME ENGINEERING AND ACCELERATED EVOLUTION"**
Harris H. Wang, Farren J. Isaacs, et al.
*Nature* 460: 894–898

**Results:** A machine developed by researchers at Harvard, MIT, and Georgia Tech can quickly make thousands of targeted changes to a bacterial genome. Using the machine to modify *E. coli* bacteria that produce lycopene, an antioxidant found in tomatoes, the researchers took just three days to create a strain that produced five times as much of the chemical as the original.

**Why it matters:** The machine could dramatically speed the increasingly sophisticated process by which researchers modify microbes to produce biofuels and other useful chemicals. This type of engineering is slow because the scientists typically need to change many interrelated genes, but they can make at most a few changes to the bacterial genome at a time. Automating the process can accomplish in just a few days work



APPROACH AND GRASP This series shows a complete grasping task. As a robotic hand approaches the flask, a planning algorithm positions the robotic fingers to achieve a sturdy grip.

MATEI T. CIOCARLIE AND PETER K. ALLEN/REPRINTED BY PERMISSION OF SAGE

that previously would have taken weeks or months.

**Methods:** Scientists mix bacteria with more than 23,000 different short strands of DNA, each of which could modify one of 24 different genes in a way that could enhance the organisms' ability to perform a certain task. One altered strand, for example, might make an enzyme more efficient. The new machine subjects vials of the mixture to temperature and chemical cycles that encourage the bacterial cells to take up the foreign DNA, swapping a particular strand into their genomes in place of the native piece it resembles. Within a vial, the rapidly reproducing bacteria take up more of the foreign DNA in each generation. The researchers examine the simultaneously produced strains and pick the one whose genetic changes make it most efficient at the desired task.

**Next steps:** Researchers want to improve the efficiency of the device, increasing the proportion of bacterial cells that end up with large numbers of genetic changes. They also plan to extend the technology to human cell lines and to yeast, which is important for making biofuels.

INFORMATION TECHNOLOGY

# Getting a Grip

A NEW APPROACH LETS ROBOTS GRASP OBJECTS MORE QUICKLY

**SOURCE: "HAND POSTURE SUBSPACES FOR DEXTEROUS ROBOTIC GRASPING"**
**Matei T. Ciocarlie and Peter K. Allen**
*The International Journal of Robotics Research* 28: 851–867

**Results:** Researchers at Columbia University have developed control algorithms for robotic hands—motorized grippers with three, four, or five fingers—that reduce the number of calculations required for the devices to grasp an object. Using the algorithms, a robotic hand was able to grasp a wide variety of objects, including a wine glass, a telephone, and an ashtray.

**Why it matters:** The advance could make robotic hands for prosthetics more useful by enabling them to grasp objects more quickly. The hand could be attached to a prosthetic arm, which the user would maneuver into place. As the hand neared an object, the system would position the fingers for the best possible grip. The person would then only have to push a button to trigger the hand to close around the object.

**Methods:** Conventional control strategies for robotic hands independently calculate the position each joint must assume to grasp an object. The researchers eliminated some of these calculations by using algorithms to virtually link the movements of the joints, so that the angle of one joint determines the angle of others. To test the algorithms, the researchers made three-dimensional scans of selected objects, which helped the system calculate which finger positions would produce a stable grasp.

**Next steps:** Whereas the current system must be programmed with the shape of an object, the researchers plan to develop a sensor system that allows the hand to grasp new objects on the fly.

# Better Wireless

UNUSED PORTIONS OF THE TV SPECTRUM COULD IMPROVE LONG-RANGE INTERNET CONNECTIVITY

**SOURCE: "WHITE SPACE NETWORKING WITH WI-FI LIKE CONNECTIVITY"**
**Paramvir Bahl et al.**
ACM SIGCOMM Conference, August 18, 2009, Barcelona, Spain

**Results:** Researchers at Microsoft and Harvard University have developed software that makes it possible to deliver long-range wireless Internet access over unused or underused fragments of the electromagnetic spectrum, known as "white spaces." Last November, the Federal Communications Commission (FCC) made white spaces in the part of the spectrum used by television stations available to unli-

censed devices as long as they didn't interfere with existing broadcasts from TV stations or from devices licensed to operate within that spectrum, such as wireless microphones. The new system uses algorithms to detect and avoid interference.

**Why it matters:** Wi-Fi works over ranges of only a few dozen meters, but the new system, which the researchers call "WhiteFi," uses frequencies that can carry information much farther, allowing users to connect to a router from more than a kilometer away. WhiteFi could be useful for rural or citywide wireless networks.

**Methods:** In the new system, white-space devices are connected in a network with a central access point, and each device detects the frequency use around it. The researchers developed algorithms that compare these results to select a range of frequencies that all devices in the network can use without interfering with other broadcasts. The system also monitors the selected spectrum and quickly moves signals to a backup slice of spectrum if there is interference from neighboring frequencies or if other devices need to use it (for example, if a wireless microphone is switched on).

**Next steps:** The group at Microsoft Research recently received an experimental license from the FCC allowing it to build and test a prototype system that will span the Microsoft campus in Redmond, WA.

MATERIALS

# Cool Fuel Cells

IMPROVED MATERIALS MAKE SOLID-OXIDE FUEL CELLS MORE PRACTICAL

**SOURCE: "IMPACT OF ANODE MICROSTRUCTURE ON SOLID OXIDE FUEL CELLS"**
Toshio Suzuki et al.
*Science* 325: 852–855

**Results:** Japanese researchers lowered the operating temperature of solid-oxide fuel cells by changing the structure of their electrode materials. They improved the power output of the cells at 600 °C by an order of magnitude.

**Why it matters:** Solid-oxide fuel cells can efficiently convert a variety of fuels, such as hydrogen and diesel, into electricity. But because they typically operate at temperatures above 700 °C, they require expensive materials, wear out relatively quickly, and are limited to stationary applications. Compared with other approaches to lowering the operating temperature of fuel cells, the new method has the advantage of using conventional materials that are relatively inexpensive. The new fuel cells could eventually be useful as auxiliary power sources to extend the range of electric vehicles, among other applications.

**Methods:** The researchers used established processes to fabricate tubular fuel cells 1.9 millimeters in diameter. To produce anodes with different structures, they heat-treated the tubes—which consist of a zirconia-based ceramic and a nickel-oxide mixture—at three temperatures lower than those ordinarily used in fuel-cell production. The resulting anodes were unusually porous, which proved to increase the performance of fuel cells based on them.

**Next steps:** The researchers established that they can bundle the microtubular fuel cells, but they need to develop ways to turn the bundles into modules that generate enough power for commercial applications.

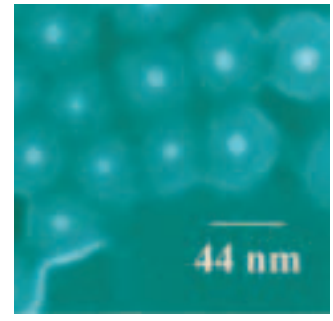
# Tiny Lasers

THE SMALLEST LASER EVER COULD FIND USES IN FUTURE COMPUTERS

**SOURCE: "DEMONSTRATION OF A SPASER-BASED NANOLASER"**
Mikhail A. Noginov et al.
*Nature* 460: 1110–1112

**Results:** A new laser devised by researchers at Norfolk State University, Purdue, and Cornell is the smallest ever made: it consists of a nanoparticle just 44 nanometers in diameter. It can emit both photons and plasmons, which are waves that travel along the surface of metals.

**Why it matters:** The research is the first demonstration of a spaser, a device that some physicists believe will form the basis of future optical computers. Such computers have the potential to be much faster than today's electronics, but current optical devices are bulky because photons are difficult to confine. Light in the form of plasmons can be confined to much tighter spaces, allowing for very fast, compact chips. Though researchers have previously made devices that can rout plasmons on chips, this spaser is the first device that can generate and amplify them.




NANO LASER These spheres, which are 44 nanometers in diameter, are made of gold coated with dye and silica. Each is a laser.

**Methods:** To make the laser, the researchers coated a gold nanosphere with a layer of silica that's embedded with dye. The gold provides the medium where the plasmons form; in the dyed silica layer, plasmons excited by light from a pumping laser are amplified, much as photons are amplified in the mirrored cavity of a conventional laser. The amplified plasmons then escape to travel along a metal surface, or they can be converted to photons so that the device emits a laser light. Either way, the device produces waves with the frequency of green light.

**Next steps:** The spasers could be improved by modifying them to emit different wavelengths. Spasers that work in the infrared, for example, might be useful for telecommunications. TR

MATURE, 2009

## Alumni-to-Alumni Directory & Classifieds



## Upcoming Events

**2009 MITX Interactive Awards**
November 17, 2009
Boston, MA
www.mitxawards.org/interactive

**MIT Sloan CFO Summit**
November 19, 2009
Cambridge, MA
www.mitcfo.com

**EmTech India 2010**
March 8-9, 2010
Bangalore, India
www.emtechindia.in

**SXSW Interactive Festival**
March 12-16, 2010
Austin, TX
http://sxsw.com/interactive/

**2010 BIO International Convention**
May 3-6, 2010
Chicago, IL
http://convention.bio.org

# Notes on a Meltdown

THE PRESIDENTIAL COMMISSION INVESTIGATING THE THREE MILE ISLAND ACCIDENT LEARNED THAT THE PROBLEMS RESTED WITH PEOPLE, NOT TECHNOLOGY.

By MATT MAHONEY

THE INVESTIGATOR John Kemeny, chairman of the president's commission on the accident at Three Mile Island, in the control room of the plant two months after the accident.

By the spring of 1979, when a partial core meltdown at one of two reactors on a long, thin island in Pennsylvania's Susquehanna River caused a national panic, the movement against nuclear power had been building for decades. (*The China Syndrome*, the movie thriller about a near-meltdown at an unsafe nuclear plant, came out two weeks earlier.) Not long after the crisis had ended, the editor of the American Nuclear Society's monthly magazine was forced to concede that Three Mile Island had "put the nuclear industry on probation." But even he might have been surprised that the probation would last 30 years *(see "Nuclear Power Renaissance?" p. 72)*.

It was in this atmosphere that President Jimmy Carter appointed a commission to investigate the accident. To head it, he selected John Kemeny, then president of Dartmouth College, a noted mathematician and computer scientist who had also worked on the atomic bomb at Los Alamos. But he was not an expert on nuclear power, and Carter's pick surprised no one more than Kemeny himself, as he revealed in a June/July 1980 article for *TR*.

Kemeny and his fellow commissioners quickly came to a surprising finding: they determined that the accident was not the fault of the technology at the plant, which they deemed "amazingly good."

*When we had our first meeting, four weeks after the accident, everyone was saying that it was a very simple case of operator error. The operators had failed to recognize that a certain valve had stuck open, and failure to recognize certain other symptoms led them to turn down the emergency core cooling system. Indeed, there is no question that these emissions converted what should have been a minor incident, that you would never have heard of, into a truly major accident. But I remember vividly, at one of our earliest open hearings, the sworn testimony of these operators, who insisted they'd never been trained for anything of the kind that had confronted them. I didn't believe them at the time, but before we were through, I would learn that they spoke the truth. They in fact had not been prepared.*

*This convinced us that the training program for operators should be thoroughly investigated. Some of the training, it turns out, is on the job, and some of it is by contract with producers of the equipment. One witness, the head of training for a manufacturer, was very proud of the significant improvements he had made over the past five years or so in his company's program. What was the single most important improvement? we asked him. "When I came," he said, "many of the lectures were given by engineers. But engineers can't talk so that people can understand them. Therefore, the first rule I laid down was that no engineer is allowed to participate in the training of operators."*

Kemeny concluded that he and his committee members were faced with "one of the most horrendous 'people problems' we had ever encountered."

*[W]e reached the unanimous conclusion that fundamental changes were necessary, within both the industry and the Nuclear Regulatory Commission, in people and in attitudes, if you are going to prevent future accidents as serious as Three Mile Island. [...] At the same time, we also had to conclude that we did not find any problem that was not curable or that led us to the conviction that nuclear power is too dangerous to exist as a viable energy source. Personally, I had no particular opinion on nuclear power, one way or the other, before chairing this commission. I do have an opinion now: if recommendations like those we came up with are implemented during the next few years, I think nuclear power can be one of the energy alternatives available to humanity. I am equally convinced, however, that if recommendations like ours are not implemented [...] then the nuclear power industry will put itself out of business, a victim of its own attitudes.*

Carter adopted most of the commission's recommendations, and no major accident has occurred since at any of the United States' more than 100 reactors. But no new reactor has been ordered in those 30 years, either. A new licensing process will soon allow for new construction. When ground is broken, the lessons of Three Mile Island will loom large. TR

WWW To see a photo gallery of images from Three Mile Island, visit **technologyreview.com/threemile**

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